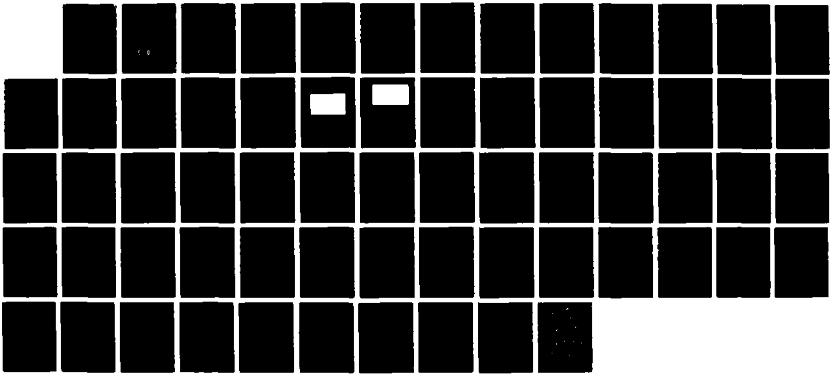
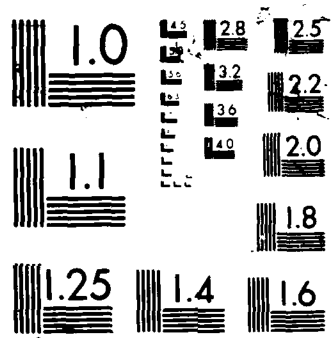
AD-A191 212 SIMULATOR EVALUATION OF LINEUP VISUAL LANDING AIDS FOR NIGHT CARRIER LANDING(U) ESSEX CORP ORLANDO FL D J SHEPPARD ET AL. 10 MAR 87 EOTR-80-1 1/1

UNCLASSIFIED N613339-85-D-0026 F/G 5/9 NL




1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

(2)

DTIC FILE COPY

AD-A191 212

SIMULATOR EVALUATION OF LINEUP VISUAL LANDING AIDS FOR NIGHT CARRIER LANDING

Daniel J. Sheppard, Lawrence J. Hettinger, Daniel P. Westra, and Sherrie A. Jones

EOTR 88-1

Prepared by:
Essex Corporation
1040 Woodcock Road
Orlando, Florida 32803

88 2 01 056

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

A191212

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) EOTR-88-1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Essex Corporation 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Naval Training Systems Center
6c. ADDRESS (City, State, and ZIP Code) 1040 Woodcock Road, Suite 227 Orlando, Florida 32803	7b. ADDRESS (City, State, and ZIP Code) Orlando, Florida 32813-7100
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Air Systems Command 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N61339-85-D-0026
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20361	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. N637-33N; PROJECT NO. SP-01; TASK NO. 0785-7P12; WORK UNIT ACCESSION NO. 4780

11. TITLE (Include Security Classification)
Simulator Evaluation of Lineup Visual Landing Aids for Night Carrier Landing

12. PERSONAL AUTHOR(S)
D. J. Sheppard, L. J. Hettinger, D. P. Westra, and S. A. Jones

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/86 to 3/87	10 March 1987	56

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
05	08	
14	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Lineup visual landing aids, night carrier landing, flight simulation, visual simulation, performance study

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A simulator performance experiment was conducted to evaluate three lineup visual landing aids for night carrier landing at the Visual Technology Research Simulator (VTRS), Naval Training Systems Center (NAVTRASYSCEN), Orlando, Florida. They were a strobe light (string of sequentially flashed lights) extending down the centerline of the landing deck, a searchlight mounted forward of the landing deck on the centerline, and a crossbar lineup system (a linear array of nine lights mounted on the fantail of the ship perpendicular to the drop lights). The searchlight and crossbar were also combined to form an additional VLA condition. A bare deck condition that represented

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Dennis C. Wightman	22b. TELEPHONE (Include Area Code) (305) 646-5130; 22c. OFFICE SYMBOL N732

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. Abstract (continued)

the standard carrier deck lighting configuration was used as the control comparison. Night carrier landing experience (zero night traps versus approximately 50 night traps), and a difficulty factor (axial wind versus angle wind), were also manipulated in the experiment. Ten naval aviators each performed 60 simulated night carrier landings under all experimental conditions.

Lineup performance was significantly more accurate with the crossbar and crossbar/searchlight combination system than with the bare deck for the far and middle segments of the approach. There appeared to be no advantage in performance near the ramp and at touchdown. There was no difference in performance between the crossbar and crossbar/searchlight combination. Lineup performance under the searchlight condition tended to lie between performance with the crossbar and bare deck conditions in the far and middle segments of the approach. The searchlight did improve lineup performance in the middle-close segment of the approach, but not significantly different from the crossbar system. The strobe light did not affect lineup performance. Flight experience had essentially no effect on lineup performance. Lineup performance in the middle under the bare deck, strobe, and searchlight conditions tended to be much poorer with the angle wind than with the axial wind. Lineup performance under the two crossbar conditions appeared to be unaffected by the wind (difficulty) manipulation.

The results of this study indicate that a low-cost simulation display containing a crossbar configuration to provide lineup displacement information contributes to improved lineup performance and does not appreciably detract from glideslope performance. Implementation of this type of system in the fleet may aid in reducing the demands imposed on pilots in the night carrier landing situation, particularly under adverse environmental conditions.

Although the searchlight improved lineup performance in the middle-close segment of the approach, far and mid-range lineup performance could and should be much better. In addition, as configured in the present experiment, the searchlight may not be operationally acceptable and a forward-facing searchlight is not recommended. Other searchlight configurations were discussed that have the potential of improving lineup performance in all ranges and be operationally acceptable.

ACKNOWLEDGEMENTS

Support for this research was funded by the Naval Training Systems Center, Orlando, Florida, under Contract N61339-85-D-0026.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
Background	1
VLA Concepts	2
VLA Assessment	3
Other Factors	7
METHOD	8
Subjects	9
Apparatus	9
Experimental Factors	10
Task Definition	13
Performance Measurement	13
Procedure	13
Experimental Design	14
RESULTS	16
Lineup Performance	16
Glideslope Performance	21
Touchdown Performance	25
Aircraft Control	28
Effect Size	28
Pilot Opinion	31
Post-Experiment Supplementary Data Collection	32
DISCUSSION	33
Experimental Factors	33
Pilot Opinion	38
CONCLUSIONS/RECOMMENDATIONS	40
REFERENCES	42
APPENDIX A: VISUAL LANDING AID LINEUP CONCEPTS	44
APPENDIX B: FRESNEL LENS OPTICAL LANDING SYSTEM	48
APPENDIX C: PERFORMANCE MEASURES COMPUTED FOR EACH TRIAL AND STATISTICAL ALGORITHM	49
APPENDIX D: MEANS OF EXPERIMENTAL FACTORS	51
APPENDIX E: SUMMARY OF PILOT QUESTIONNAIRES	56

LIST OF FIGURES

Figure		Page
1	Bare Deck Illustration	11
2	Searchlight and Crossbar Illustration	12
3	Percent TOT Lineup ($\pm$0.5 deg) Across Flight Segments for the VLA Conditions	18
4	VLA X Wind Interaction for Percent TOT Lineup ($\pm$ .5 deg) for the 4500-3000 ft Flight Segment	21
5	Percent TOT Glideslope ($\pm$ 0.3 deg) Across Flight Segments for the VLA Conditions	24
6	Percent TOT Glideslope ($\pm$0.45 deg) and Lineup ($\pm$0.05 deg) Across Segments for the VLA Conditions	25
A-1	Crossbar Lineup System	44
A-2	Contra-rotating Lineup Beacons	45
A-3	Double-beam Lineup System	46
A-4	Searchlight-Simulated Runway Extension	47
A-5	Racetrack Cue Lineup Aid	47

LIST OF TABLES

Table		Page
1	VLA Rating	6
2	Experimental Factors	8
3	VLA Pilot Summary Data	9
4	Experimental Design	15
5	Summary of Lineup Performance Effects for the Four Approach Segments	17
6	Means for Lineup Performance Measures for the Four Approach Segments: VLA Conditions	19
7	Summary of Glideslope Performance Effects for the Four Approach Segments	22
8	Means for Glideslope Performance Measures for the Four Approach Segments: VLA Conditions	23
9	Summary of Touchdown Performance Effects	26
10	Means for Wire Caught and Lateral Drift at Touchdown: VLA Conditions	27
11	Frequency of Three Wires Trapped and Bolters (Missed Wire): VLA Conditions	27
12	Means for TOT Angle of Attack and RMS Roll Error Across Segments: VLA Conditions	29
13	Analysis-of-Variance Summary for TOT Angle of Attack and RMS Roll Error	29
14	Percent of Variance Accounted For in the Data for Selected Performance Measures	30
15	Pilot Ratings	31
16	Means for TOT Lineup ($\pm$0.5 deg) for the Two Pilots Post-tested with the Artificial Horizon	32
D-1	Lineup Means: Experience Level and Wind Conditions	51
D-2	Glideslope Means: Experience Level and Wind Conditions	52
D-3	Touchdown Means: VLA Conditions	53
D-4	Touchdown Means: Experience Level and Wind Conditions	54
D-5	Aircraft Control Means: Experience Level and Wind Conditions	55

INTRODUCTION

The carrier landing task is difficult and requires considerable coordination of perceptual and motor skills. It is one of the most demanding tasks a naval aviator must perform. The pilot must maintain a precise glideslope and simultaneously maintain the correct angle of attack, airspeed, vertical velocity, and lineup in relation to the landing deck. If the pilot maintains position and velocity errors within acceptable limits, he will execute a successful touchdown and trap. Factors such as the limited size of the landing deck, ship forward motion, deck motion due to seastate, and lack of adequate visual information from the surrounding seascape make landing on the deck of a carrier more difficult than landing on a conventional airfield.

BACKGROUND

Although there is a lack of environmentally-based visual information at sea, position and flight path control operations are strongly based on the visual information the pilot receives from the external visual world in the approach zone (1). The lack of visual information to estimate position on the glideslope at sea led to the development of the Fresnel Lens Optical Landing System (FLOLS) to provide glideslope displacement information to the pilot. However, although the FLOLS provides the primary displacement information for glideslope control, it has long been recognized that the system is less than optimum (2,3). Because the information from the meatball is of zero order (displacement only), there are substantial lags between incorrect control inputs and the subsequent error information from the FLOLS. That is, a rate (first order) error must exist for some short period of time before it produces a perceivable displacement error (4).

In addition to the suboptimal FLOLS display, much of the visual information available to the pilot during daytime approaches is either not present or degraded at night. The absence of environmental information and the increased hazards of flying at night (vertigo and spatial disorientation) make landing on an aircraft carrier at night even more difficult. Previous carrier landing research has indicated that pilots tend to fly lower approaches with larger error variability at night than by day (5,6). Although the FLOLS display, centerline lights, and drop lights augment the pilot's estimation of position and flight path at night, poor final approaches and accidents continue to have a higher probability of occurrence at night (7).

This situation has led to the development of glideslope and lineup Visual Landing Aid (VLA) concepts for the carrier landing task. One of the most successful VLA concepts was developed and tested at the Visual Technology Research Simulator (VTRS). Vertical light arrays appearing as bars or arrows extending up or down from the inside ends of the datum bars were added to the FLOLS display. The vertical light arrays provided glideslope descent <u>rate</u> information to augment the zero displacement information provided by the FLOLS display. The descent rate cueing aid improved glideslope tracking performance significantly throughout the approach in simulated approaches at the VTRS (4). Follow-on shore-based and shipboard flight tests of the system also had comparable improvements in glideslope performance.

The Naval Air Engineering Center (8) conducted an extensive survey of fleet requirements for the development of additional visual landing aid configurations. From this survey several glideslope and lineup cue concepts (9) were proposed for further evaluation at the VTRS. They were selected as a result of past VLA efforts, developments in VLA technology at the Naval Air Engineering Center, and fleet requirements for additional visual landing aids. Normally, system concepts would be tested in a shipboard evaluation. However, flight testing of system concepts can be very expensive and dangerous, and the value of using flight simulation to evaluate visual landing aid concepts was demonstrated in the Lintern et al. (4) experiment.

VLA CONCEPTS

Ten sources of glideslope and lineup information were considered for flight evaluation (9). The present study will be concerned only with the VLA concepts to improve lineup information to the pilot for night carrier approaches. A copy of the VLA lineup concepts and design data depicted in the report are presented in Appendix A. The following is a brief description of the VLA concepts that were considered for simulator evaluation:

<u>Crossbar Lineup System</u>. A horizontal row of directional lights mounted perpendicular to the droplights under the ramp. As the pilot deviates from centerline, the directional lights are progressively illuminated to form a line which points towards the direction the pilot must fly to get back to centerline. Viewing threshold could be from parallel to centerline or an angular orientation (fan out) from centerline (see Fig. A-1, Appendix A).

Contrarotating Lineup Beacons. Beacons placed at the edge of the ramp, one starboard side and one portside. Beacons rotate in opposite directions and are synchronized so that both are parallel to centerline at the same time. If the pilot is left of centerline, flashes occur in a left-right sequence. If the pilot is right of centerline, flashes occur in a right-to-left sequence (see Fig. A-2, Appendix A).

Double-beam Lineup System. Two projectors mounted below the ramp (port and starboard) such that the sectors of light emitted show red outboard and nothing in the middle. When on centerline the pilot will see nothing. As the pilot moves left or right of centerline the red light appears. The pilot is to fly away from the red (see Fig. A-3, Appendix A).

Searchlight Simulated Runway Extension. Searchlight mounted on centerline aft with the light beam pointed down at the water (see Fig. A-4, Appendix A).

Racetrack System. Lineup cues to aid a pilot making a "race track" approach. Experimentation was required to determine the number and placement of marker lights, viewing angles, and other additional cues. One possible configuration was bow and stern marker lights to indicate the orientation of the ship and disappear as a cue for the pilot to begin his turn. The view angle of the centerline light is also increased beyond the present 20 degrees from centerline (see Fig. A-5, Appendix A).

Sideways FLOLS. A horizontally configured system similar to the FLOLS display (not defined in detail in NAVAIRENGCEN Report).

These concepts were not necessarily in their final configuration but were presented for planning purposes. Furthermore, it was not feasible to test all the concepts in a simulator evaluation. Thus, a human factors assessment of the VLA concepts was conducted to determine the concepts that were the most promising candidates for improving lineup information to the pilots (10). Subsequent pre-experimental work at the VTRS with experienced naval carrier pilots and Landing Signal Officers (LSOs) helped determine the final configuration of the VLAs to be tested at the VTRS.

VLA ASSESSMENT

A human factors assessment of the VLA concepts proposed by the Naval Air Engineering Center (9) was conducted by Hennessy (10). The assessment was conducted to provide some data on the VLA concepts proposed for flight simulator evaluation. The

candidate VLAs were assessed by applying the following five criteria (10):

<u>Positive On-course Indication</u>. The positive indication of "no error" or "within tolerance." This is highly desirable because it quickly assures the pilot that he has visually acquired the VLA, that it is working, and that he has not failed to detect an error.

<u>Error Resolution</u>. The VLA provides information that the critical flight variable (lineup) is within or exceeds some defined tolerance limit and error direction. Ideally, a VLA would provide a degree of error resolution compatible with the degree of the pilot's control capability. Also, high resolution of error implies the ability to detect and correct significant error earlier in the approach.

<u>Discrete Cueing of Error Onset</u>. Does the VLA provide information about the transition from within to outside tolerance in a continuous or discrete manner? The latter is preferred. When the transition information is continuous, the pilot must constantly monitor and judge whether an outside-of-tolerance condition exists. Detecting the onset of error cued continuously requires constant attention by the pilot. Discrete cueing of error onset both alerts the pilot by the suddenness of onset and obviates the need for constant monitoring and deciding if an error condition exists.

<u>Information Compatibility</u>. The coding scheme of the VLA. Some coding schemes are more easily and meaningfully interpreted than others. That is, the coding schemes vary in the degree of relationship to the information sought. High compatibility means the relevant information is easily perceivable. For example, perceiving the position of the aircraft with respect to the centerline of the ship requires no translation or "decoding." A color coding scheme, on the other hand, requires the pilot to remember and associate a particular color or saturation of color with a direction or amount of error in lineup.

<u>Ease of Acquisition</u>. VLAs typically provide information related to a single flight variable such as lineup. Thus, the pilot must frequently shift his visual attention among the available sources of information for different flight variables. The more conspicuous the VLA, the more quickly and easily the pilot will be able to acquire and reacquire the VLA. When it is difficult to quickly identify a VLA among the other lights on the carrier, the pilot's workload is increased.

Hennessy (10) used a 6-point scale (0-5) for each criterion to determine which VLA concepts had the greater potential to improve lineup information to pilots during night carrier landings. A zero indicated an absence of the criterion characteristic in the VLA concept, and a five indicated a high degree of presence of the desired characteristic in the VLA concept. Three individuals made a consensual judgment of the rating value to be applied for each criterion to each VLA. In addition, the five criteria were not considered to be of equal importance, and each was assigned a relative weight. The aggregate rating score for each VLA concept was then computed by summing the rating score times the weighting value for each of the five criteria. Table 1 presents the results of the rating procedures.

The searchlight and crossbar VLA configurations had the highest rating scores for lineup information based on the five criteria previously discussed (Table 1). Thus, they were recommended as the most promising candidates for improving lineup information to the pilot (10) and consequently implemented at the VTRS for pretesting and evaluation. The pretesting involved experienced carrier pilots and engineers from the Naval Air Engineering Center, Lakehurst, New Jersey; experienced pilots from the Naval Air Test Center, Patuxent River, Maryland; and Landing Signal Officers (LSOs) from the LSO School at Cecil Field, Florida.

One of the problems or reservations the pilots and LSOs had with the crossbar lineup system was its location on the fantail of the ship. They were concerned that pilots would shift their gaze to the crossbar for a lineup check close to the ramp. At this point of the approach, pilots should only be scanning the FLOLS display and a shift of their gaze to the crossbar lineup lights below the edge of the ramp would be very dangerous. Shutting off the crossbar lights when the aircraft was 1500 feet from the ramp or placing the crossbar system on the deck of the landing area were recommended adjustments. In later discussions it was determined that placing the crossbar lineup system on the deck of the carrier would not be feasible from an operational perspective. Thus, the crossbar system was placed on the fantail of the ship and the lights were blanked out when the aircraft was 1500 feet from the ramp.

In addition to the crossbar and searchlight, a strobe light down the centerline of the landing deck was considered as a VLA for lineup information. Although the strobe light is a standard factor on aircraft carriers, no objective data has been collected on its usefulness as a lineup aid. The pre-experimental pilots and LSOs had favorable attitudes towards the strobe light. Thus, it was included in the experiment as a landing aid to be tested along with the crossbar and searchlight. The searchlight and crossbar systems were also combined to form an additional VLA condition.

TABLE 1. VLA rating (10)

VLA TYPE		Positive On Course Indication	Error Reso-lution	Cueing of Error Onset	Information Compati-bility	Ease of Acqui-sition	Total Rank Value	Rank Order Order of Merit
	CRITERION WEIGHTING	0.8	0.8	1	0.7	1		
LINEUP	VLA CONCEPT							
1	CROSSBAR	0	5	5	4	4	15.8	2
2	CONTRA-ROTATING BEACONS	5	2	4	2	4	15.0	4
3	DOUBLE RED BEAM	0	0	5	4	2	9.8	5
4	SEARCHLIGHT	5	5	4	5	5	20.5	1
5	SIDEWAYS FLOLS/ACARS	5	3	2	4	4	15.2	3

OTHER FACTORS

In previous experiments at the Visual Technology Research Simulator, pilot experience level and environmental conditions have influenced performance on the carrier landing task (11,12). It's possible that different VLA conditions may be more beneficial to pilots of varying experience level or that task difficulty may influence performance differently under different VLA conditions. Thus, experience level and a difficulty factor (wind) were included in the experiment.

METHOD

An in-simulator repeated-measures design was used to study the effects of three lineup visual landing aids on night carrier landing performance. Each of the 10 naval pilots performed 60 simulated night carrier landings, 12 under each experimental VLA condition. The experimental factors are summarized in Table 2.

TABLE 2. Experimental Factors

VLA Conditions	
Bare Deck	Standard night ship lighting configuration with centerline strobe light inoperative.
Strobe Light	A string of sequentially flashed lights extending down the centerline of the landing deck.
Searchlight*	In addition to the strobe light, a searchlight mounted forward of the landing deck on the centerline aimed forward and angled upward five degrees.
Crossbar*	In addition to the strobe light, a linear array of nine lights mounted on the stern of the carrier perpendicular to the drop lights at ten foot intervals with their successive beams on either side of centerline fanning outward in 0.1 degree increments.
Difficulty Factor	
Axial Wind	Ship speed 25 knots - no wind down the angled deck.
Angled Wind	Ship speed 15 knots - 10 knots wind down the angled deck.
Experience Level	
Low	Zero night traps.
Moderate	Approximately 50 night traps.

*Searchlight and crossbar systems along with the strobe light were combined to form a fifth VLA condition.

SUBJECTS

Ten experienced naval pilots participated in the experiment. All pilots were from operational squadrons and varied in flight experience and type of aircraft currently assigned. Table 3 summarizes the flight experience of the pilots. The ten pilots were divided into two equal subgroups based on night carrier landing experience. For the purpose of this study, zero night traps constituted low experience, while the moderate experience group (having completed one tour) had approximately fifty night traps.

TABLE 3. VLA Pilot Summary Data

Pilot	A/C Type	Total Flt Hrs	Total Sim Hrs	Night Traps	Day Traps
1	FA-18	260	515.5	0	10
2	FA-18	1350	100	50	100
3	A-7E	1100	120	50	150
4	A-7E	805	0	0	10
5	A-6E	675	260	56	116
6	A-6E	300	215	0	10
7	E-2C	200	170	0	10
8	E-2C	1000	25	40	70
9	F-14A	770	50	0	16
10	F-14A	1100	50	60	112

Mean Flight Hours - 975
Mean Simulator Hours - 173.65

APPARATUS

Simulator

The Visual Technology Research Simulator (VTRS), described in further detail elsewhere (13), has a fully instrumented T-2C Navy jet trainer cockpit, T-2C flight dynamics, a six degree-of-freedom synergistic motion platform, a 32-element g-seat, and an instructor/ operator control station. Visual, aerodynamic, and motion computations were performed at a 30 Hz iteration rate by a SEL 32/77 computer system of high-speed multiple processors. The motion system and g-seat were not used in this experiment.

Visual System

The visual scene was represented by computer-generated images that were projected onto the interior surface of a ten

foot radius domed screen. A General Electric Compu-Scene I (upgraded to an extra edge capacity of a Compu-Scene III) and a PDP 11/55 computer were used to provide a 6000-edge capacity. A light valve color projector was used to display the carrier image, which was a representation of the USS Forrestal, to give a 29.5 degree vertical by 36.5 degree horizontal field of view. The brightness and contrast levels of the projector were kept constant throughout the experiment.

The average delay between a pilot's control inputs and generation of the corresponding visual scene was approximately 117 msec. Calculation of new aircraft coordinates and calculation of the coordinates for the visual scene corresponding to the viewpoint for the new aircraft coordinates required approximately 50 msec each, while generation of the new scene requires 17 msec.

Fresnel Lens Optical Landing System

The FLOLS and its use are described in Appendix B. To prevent some of its smaller elements from shimmering and disappearing temporarily as they crossed raster lines, the simulated FLOLS was enlarged by a factor of 4.5 when the distance behind the ramp was greater than 2250 feet. From 2250 feet its size was linearly reduced until it attained 1.5 times its normal size at 750 feet. It remained that size throughout the remainder of the approach. Sheppard (14) found that simulator training with an oversized FLOLS would have no adverse effect on transfer to a normal size FLOLS in the field. The FLOLS was set for 3.5 degrees glideslope.

Instructor/Operator Station (IOS)

An experimenter stationed at the IOS was able to communicate with the pilots via an audio headset. A color monitor displayed the background and the target (carrier) image and provided the experimenter with a general perspective of what the pilot viewed in the simulator.

Two graphic displays provided the experimenter feedback on pilots' performance. One display was a real-time representation of the major cockpit instruments, and the other display presented a time history of glideslope and lineup performance measures plotted from a distance of 6000 feet from the carrier to touchdown.

EXPERIMENTAL FACTORS

Visual Landing Aids

Five levels of the VLA condition were used in the experiment. The five VLA conditions were bare deck, strobe light, searchlight, crossbar, and combination searchlight and

crossbar. The bare deck condition had no additional lineup VLAs, and represented the standard carrier deck lighting configuration and was used as the control comparison. Fig. 1 illustrates the bare deck lighting configuration. In this scene the drop lights were colored red and the datum bars of the FLOLS display were colored green. The red drop lights and green datum bars were a standard feature on all the VLA scenes.

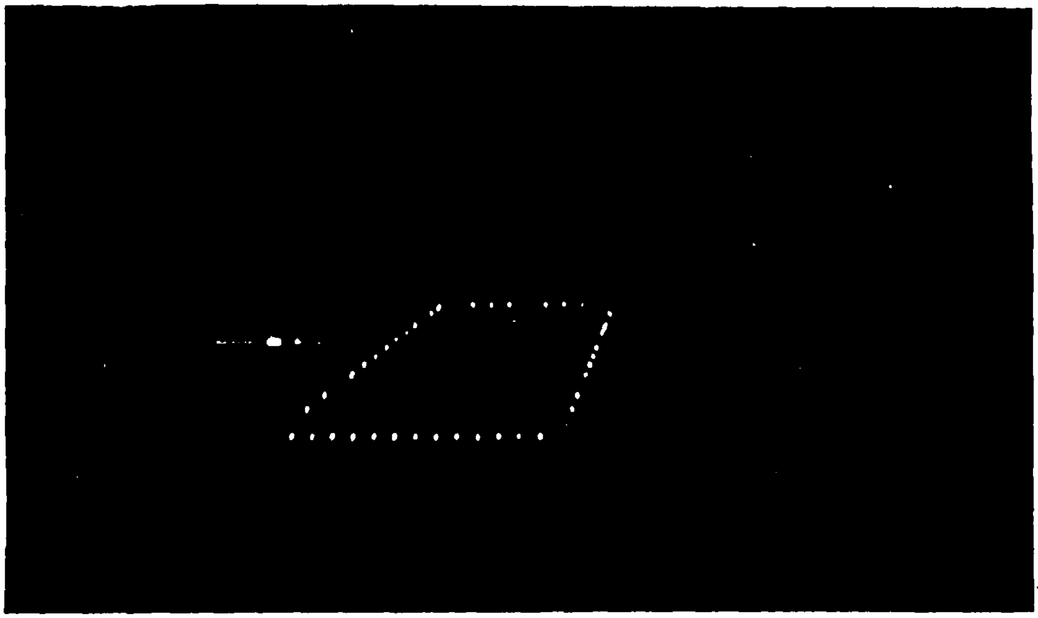


Figure 1. Bare deck illustration.

A centerline strobe light was added to the bare deck configuration to form the second VLA condition. The lights extended down the centerline of the landing deck and were sequentially flashed from near to far at a frequency of approximately 0.94 Hz. The strobe light was a standard feature on all the VLA conditions except bare deck.

A searchlight was mounted forward of the landing deck, on the centerline and angled upward five degrees to form a third VLA condition. The searchlight was 900 feet long with decaying intensity going out from the ship. Fig. 2 illustrates the searchlight configuration.

The crossbar system consisted of a linear array of nine horizontally arranged lights mounted on the stern of the aircraft carrier just above the drop lights. The center light was colored green and gave the indication that the system was working, and if it were the only light visible, that the pilot was on centerline (within the tolerance of the system). Four

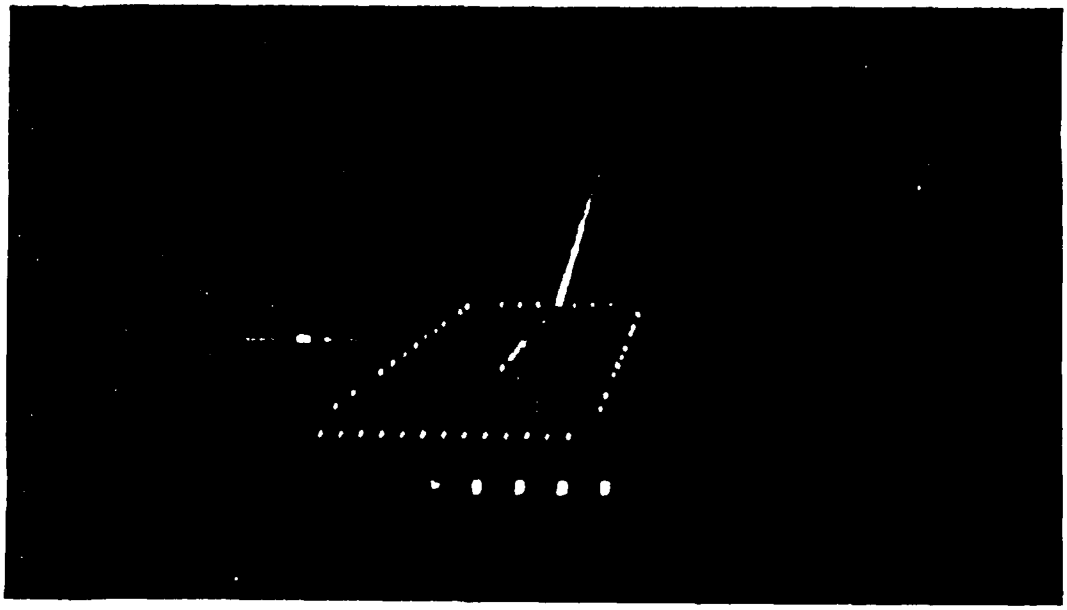


Figure 2. Searchlight and crossbar illustration.

lights were spaced at ten foot increments on either side of the center green light with their beams fanning outward in angular increments of 0.1 degrees (hence $\pm$ 0.4 degrees total). As the pilot deviated from centerline, the directional lights would appear progressively and would form a line pointing in the direction he must fly to get back to centerline. To prevent the pilots from referencing the crossbar near touchdown (dangerous tactically), the crossbar system was shut off when the aircraft was 1500 feet from the ramp of the ship. Fig. 2 illustrates the crossbar configuration. The searchlight and crossbar were combined to form the fifth VLA condition (Fig. 2).

Experience Level

Two levels of experience level were used in the experiment. The low experience group had zero night carrier landings (Traps), while the moderate experience group had approximately 50 night carrier landings (Traps) which is roughly equivalent to one tour of duty.

Wind

Pilots, as part of the experimental task, received either axial or angled wind components. For the axial wind condition, the ship's forward speed was 25 knots with no wind down the angled deck. For the angled wind condition, the ship's forward speed was 15 knots with 10 knots of wind down the angled deck.

TASK DEFINITION

The experimental task was a straight-in approach from 7500 feet aft of the carrier. The simulator was initialized with the aircraft in its landing configuration (hook down, speed brake out, wheels down) at an altitude of 527 feet, AOA of 15 units, half flaps, power at 83 percent, vertical velocity of approximately 500 feet per minute, on glideslope, randomly offset either 50 feet left or 50 feet right of centerline, and in a cloud layer. Upon release from freeze, pilots flew in the cloud cover for approximately five seconds before the carrier became visible.

PERFORMANCE MEASUREMENT

Parameters of aircraft position and attitude were sampled within the simulator at 30 H, and were used to derive altitude and lineup error scores from the desired approach path and deviations from desired AOA (15 units). Root Mean Square (RMS) error, mean algebraic error, and variability around those means were calculated for the three performance dimensions over four segments of the final 6000 feet of the approach. The four approach segments were 6000 feet to 4500 feet, 4500 feet to 3000 feet, 3000 feet to 1000 feet, and 1000 feet to the ramp. These segments correspond to the far-out, in-the-middle, and close-in segments of the carrier approach. Time-on-Tolerance (TOT) scores were also computed for these segments for time within the desired limits in the lineup, glideslope, and AOA dimensions. Average stick movements for each segment were also recorded, along with snapshot values of aircraft position at the ramp and touchdown measures. A list of the performance measures computed for each trial, task segments, and statistical algorithms are shown in Appendix C.

PROCEDURE

Ten naval pilots with varying degrees of night carrier landing experience were selected to visit Orlando. Each pilot was assigned to one of the experimental sequences depending on experience level. They were briefed on the experiment, the procedures necessary to perform the task, and the visual landing aid configurations. All pilots received a minimum of 24 familiarization flights in the simulator before beginning their experimental trials. The pilots were cycled through their simulator sequences to complete 60 straight-in carrier approaches over a two day period. Experimenters monitored the simulator trials throughout the experiment from the IOS and gave feedback (i.e., wire caught) after each trial. Pilots also completed questionnaires both during and at the end of the experiment.

Briefing

Pilots were given a briefing on the visual landing aid configurations and the experimental task upon arrival at VTRS. Pilots were shown the cockpit of the simulator and its important features were identified and described. While waiting his turn, the other pilot was told to limit his observation of the visual displays.

Familiarization Trials

Each pilot flew 24 practice trials, six with each of the four basic VLA configurations (Bare Deck, Strobe Light, Searchlight, and Crossbar) before starting the experiment. Some pilots received up to six extra trials, as needed, if their performances were erratic or if they were still unsure about the interpretation of any particular VLA condition. The purpose of these trials was to familiarize the pilot with the flight simulator task and VLA conditions and to provide sufficient practice to stabilize their performance.

Questionnaire

During the experiment, and at the end of the study, pilots were asked to rate each VLA condition with regard to its effect on performance and workload. Pilots were also asked to comment in as much detail as necessary on the nature of the effects they thought the various displays had on their performance.

Scheduling

Pilots were scheduled in groups of two. Each group arrived at the VTRS on a Monday or Wednesday afternoon. The pilots completed the briefing and familiarization trials the afternoon of their arrival, began their experimental trials the second day, and finished on the morning of the third day. Each pilot performed twelve consecutive trials, six on each of two displays, in a single simulator session with a one-half hour rest between sessions.

EXPERIMENTAL DESIGN

The experiment was a repeated-measures design with each pilot flying all combinations of wind and start position with each VLA condition. The design, detailed in Table 4, was counterbalanced for linear trends and carryover effects.

TABLE 4. EXPERIMENTAL DESIGN

		Trial Sessions[1]									
	Pilots	1[2]		2		3		4		5	
Low Experience	1	A[3]	B	C	D	E	E	D	C	B	A
	2	B	C	D	E	A	D	C	B	A	E
	3	C	D	E	A	B	C	B	A	E	D
	4	D	E	A	B	C	B	A	E	D	C
	5	E	A	B	C	D	A	E	D	C	B
Moderate Experience	6	A	C	E	B	D	D	B	E	C	A
	7	C	E	B	D	A	B	E	C	A	D
	8	E	B	D	A	C	E	C	A	D	B
	9	B	D	A	C	E	C	A	D	B	E
	10	D	A	C	E	B	A	D	B	E	C

[1]Each session consisted of 12 trials, 6 trials per VLA condition.
[2]Start position and wind conditions were randomized within each session and balanced across each VLA condition.
[3]Each letter refers to a VLA condition.

RESULTS

Summary measures for the performance dimensions of lineup control, glideslope control, aircraft control, and touchdown scores were selected for analysis. Within the dimensions, summary measures were available over the four approach segments and in several different transformations (e.g., Root Mean Square error and percent time-on-target scores). Although some of this information is redundant and overlapping, the approach was taken to present the results of several summary measures for each performance dimension which best describe the results of the experiment and to provide supporting evidence for a result.

The results in general have been condensed in the interest of keeping a reasonable bound on the amount of information presented. Analysis of variance tables summarize the main effects of the experimental factors. Significant interactions are reported only if they are either consistent across performance measures or within a flight segment across several performance measures for each performance dimension (e.g., lineup control, glideslope control). Further condensation was done by presenting the means only for the VLA conditions in the body of the text. Means for the other experimental factors (experience level and wind) are presented in Appendix D.

LINEUP PERFORMANCE

Three time-on-tolerance (TOT) summary scores were considered as the best indicators of performance in the lineup dimension. Use of these scores eliminates the subjective task of editing for outliers and the scores themselves are immediately interpretable in terms of "operationally meaningful" effect magnitude (15). TOT scores give the percentage of time within specified tolerance limits. Lineup tolerance limits for this experiment were set at $\pm$15 feet, $\pm$30 feet, and $\pm$ 0.5 degrees (the latter is an "OK" status as far as lineup is concerned). RMS error scores were also analyzed and reported as indicators of lineup performance. Log transformation was applied to all RMS scores to correct for violations of normality and homogeneity of variance prior to statistical analysis (16).

Analyses-of-variance for lineup control across the four flight segments are summarized in Table 5. Although the Visual Landing Aids (VLA) had a significant effect on lineup performance across all flight segments, the strongest and most consistent lineup effects for the VLAs appear to be in the

TABLE 5. Summary of Lineup Performance Effects for the Four Approach Segments

Percent Time-on-Tolerance Lineup (± 15 feet)

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	7.70**	1	1.72	1	.22	1	.11
VLA	4	2.47*	4	4.37**	4	2.97**	4	.65
Wind	1	9.73**	1	0.80	1	2.22	1	1.19
VLA x Wind	4	1.18	4	1.98	4	1.18	4	1.63

Percent Time-on-Tolerance Lineup (± 30 feet)

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	2.39	1	2.61	1	0.17	1	0.46
VLA	4	5.07***	4	5.47***	4	4.79***	4	3.01**
Wind	1	28.97***	1	1.93	1	7.84**	1	6.58**
VLA x Wind	4	0.92	4	2.62**	4	2.77**	4	0.15

Percent Time-on-Tolerance Lineup (± 0.5 degrees)

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	2.23	1	1.93	1	0.31	1	0.64
VLA	4	5.55***	4	6.69***	4	3.83**	4	1.12
Wind	1	171.52***	1	3.18	1	5.34**	1	0.11
VLA x Wind	4	0.86	4	3.77**	4	2.56*	4	2.11

Log RMS Lineup Error

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	2.35	1	2.43	1	0.62	1	0.05
VLA	4	2.47*	4	5.30***	4	3.37**	4	0.81
Wind	1	29.76***	1	4.06*	1	2.33	1	0.39
VLA x Wind	4	0.96	4	3.28**	4	1.76	4	1.59

* $p < .10$
** $p < .05$
*** $p < .01$

middle and far segments (Table 5). Fig. 3 depicts these results graphically for one performance measure (TOT ± 0.5 degrees) and the means by VLA conditions across the four flight segments for the lineup performance measures are presented in Table 6. These results show clearly that lineup performance was significantly enhanced by the crossbar and combination crossbar/searchlight system in the far and middle segments. There appeared to be no statistically significant advantage in performance for the close-in segment. Apparently, these VLAs improved the ability of the pilots to set up and start the approach on lineup, although the substantial improvement in lineup control did not carry over into the close-in segment. The lack of a significant in-close benefit may be due to the fact that the crossbar system was shut off when the aircraft was 1500 feet from the ramp. Nevertheless, a good start and better performance in the middle is obviously beneficial.

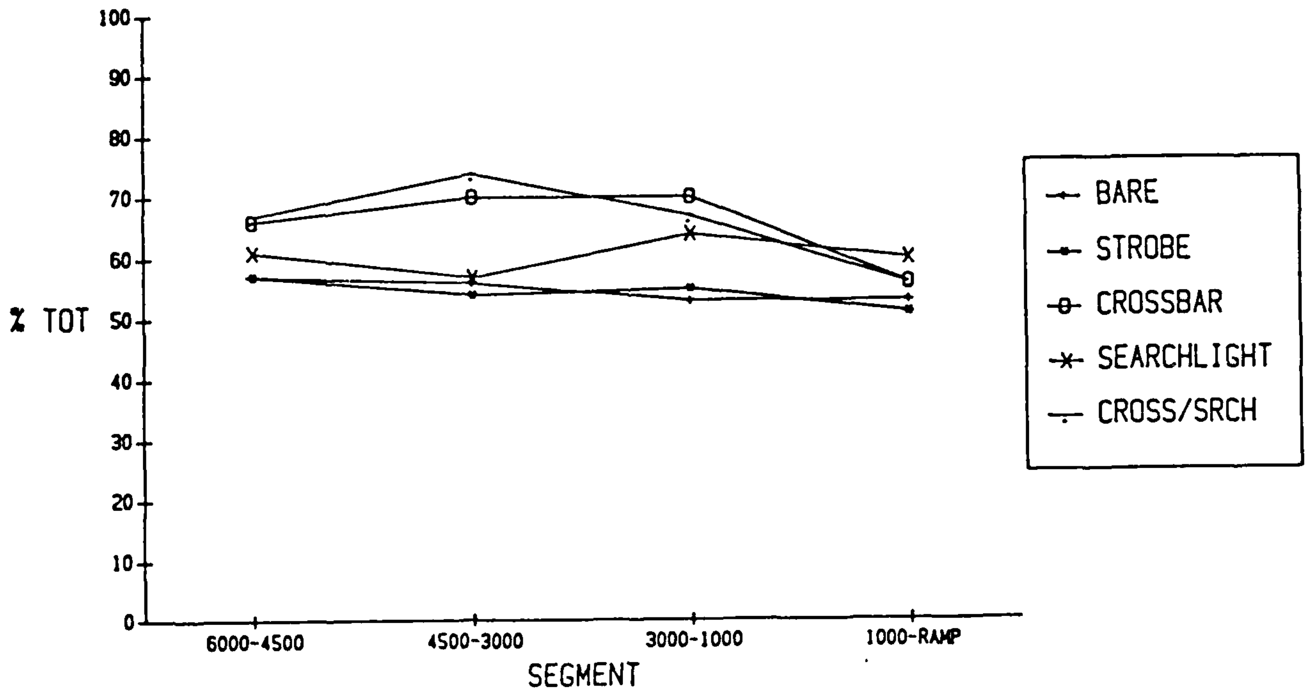


Figure 3. Percent time-on-tolerance lineup (+/-0.5 degrees) across flight segments for the VLA conditions.

TABLE 6. Means for Lineup Performance Measures for the Four Approach Segments: VLA Conditions

Percent Time-on-Tolerance Lineup (± 15 feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	17	27	42	76
Strobe	19	21	39	77
Crossbar	22	34	54	80
Searchlight	19	29	48	80
Cross/Search	22	34	49	81

Percent Time-on-Tolerance Lineup (± 30 feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	37	46	67	94
Strobe	40	44	69	97
Crossbar	45	61	83	95
Searchlight	43	50	84	99
Cross/Search	47	62	84	99

Percent Time-on-Tolerance Lineup (± 0.5 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	57	56	53	53
Strobe	57	54	55	51
Crossbar	66	70	70	56
Searchlight	61	57	64	60
Cross/Search	67	74	67	56

RMS Lineup Error (Geometric Means - feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	51.6	31.3	21.0	9.8
Strobe	41.0	33.6	21.5	9.9
Crossbar	38.0	24.9	16.7	9.0
Searchlight	39.8	29.5	18.6	8.6
Cross/Search	36.8	24.4	17.1	9.1

Lineup performance under the searchlight condition tended to lie between performance with the crossbar and the bare deck conditions in the far and middle segments of the approach (e.g., Fig. 3). The searchlight substantially enhanced lineup performance in the middle-close (3000-1000 feet) segment and did have the best lineup performance in close, although it was not significantly different versus the other VLA conditions (Table 5). The centerline strobe light did not affect lineup performance. Thus, although the strobe lighting system may help the pilot spot the deck, it apparently does not provide any additional lineup information.

Although there was a significant VLA effect in the close-in segment for percent time-on-tolerance lineup ± 30 feet, an examination of the means given in Table 6 suggests that this result does not have practical significance. A ceiling effect has clearly limited the outcome. A tolerance band of ±30 feet in the close-in segment is simply too wide.

Flight experience was only significant in the far segment for percent TOT lineup ±15 feet (Table 5). The moderate experience pilots maintained lineup within the 15 foot tolerance a higher percentage of the time than did the low experience pilots. Flight experience had essentially no effect on lineup performance in the middle and in close. Wind had a consistent and strong effect in the far segment with better performance under the axial wind condition than the angle wind (Table 5). Wind also affected the middle and close-in segments although the effects in these segments were not quite as strong or consistent (Table 5). Wind was included in the experiment as a difficulty factor and was expected to affect lineup performance. The most important considerations involving wind in this experiment were interactions between wind and VLA conditions.

Table 5 shows that the interactions between wind and VLA conditions tended to be significant in the middle of the approach, although it was not consistent across all performance measures. Inspection of the means for the VLA x wind interaction showed that lineup performance under the crossbar and combination searchlight/crossbar condition was similar regardless of wind condition. However, lineup performance under the bare deck, strobe, and searchlight conditions was much poorer with the angle wind versus the axial wind. This result is clearly depicted in Fig. 4. It appears that the wind main effect is primarily due to poorer lineup performance under the bare deck, strobe, and searchlight conditions with the angle wind. In addition, lineup performance under the two crossbar conditions appear to be unaffected by the wind manipulation.

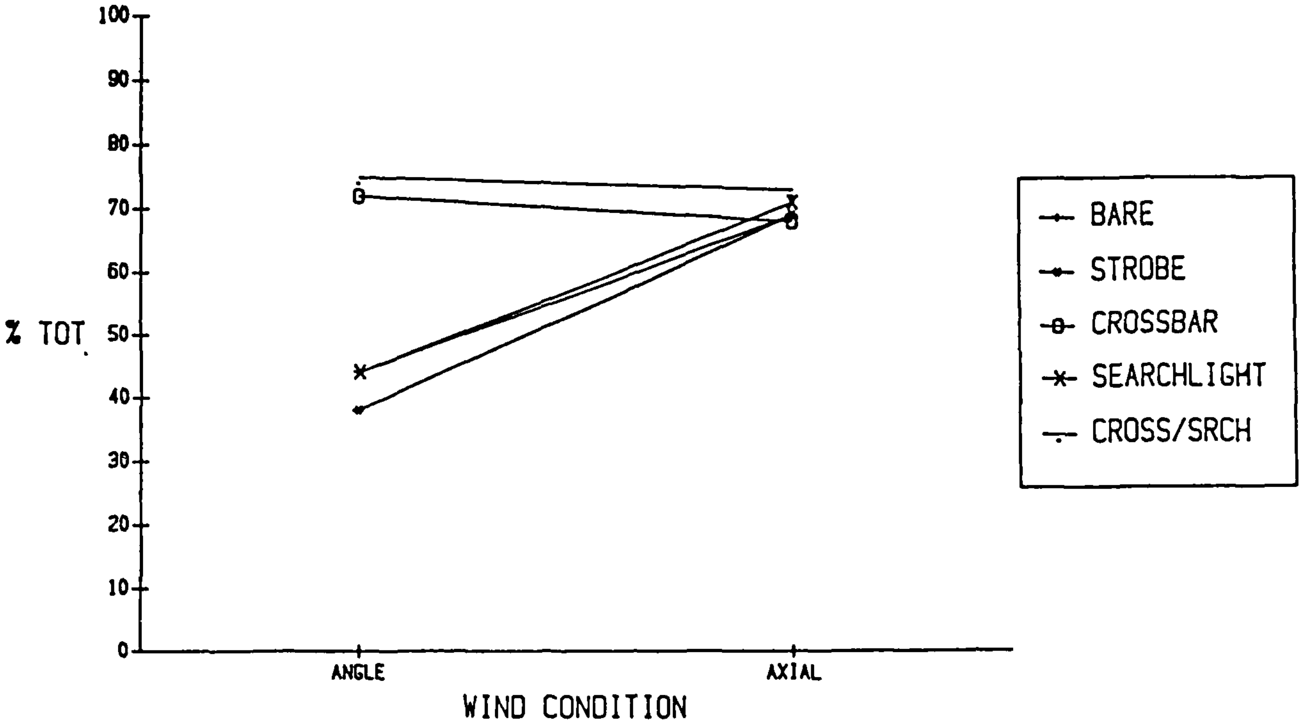


Figure 4. VLA by wind interaction for percent time-on-tolerance lineup (+/-0.5 degrees) for the 4500-3000 foot flight segment.

GLIDESLOPE PERFORMANCE

Table 7 gives the analysis-of-variance summaries of glideslope performance across the flight segments for TOT glideslope $\pm$ 0.3 degrees ($\pm$ 1.0 meatball), RMS glideslope error, and a composite score of glideslope and lineup performance. Means for the glideslope performance measures are shown in Table 8. The means show that glideslope performance with the crossbar system was worse in the middle segments of the approach. Fig. 5 illustrates these results graphically for TOT glideslope $\pm$ 0.3 degrees. However, although the trend is apparent, the analysis-of-variance summaries shown in Table 7 indicate that the differences were only marginally significant in the middle ($p < .10$). The term "marginally" is used because a 0.1 significance level is not usually accepted as reliable. In addition, analysis-of-variance of percent TOT glideslope $\pm$ 0.45 degrees ($\pm$ 1.5 meatball) did not reveal any statistical differences between the groups. Nevertheless, it appears that the improved lineup performance in the middle with the crossbar tends to come at some expense of glideslope control, although this was a weak effect.

TABLE 7. Summary of Glideslope Performance Effects for the Four Approach Segments

Percent Time-on-Tolerance Glideslope (± 0.3 degrees)

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	2.16	1	1.51	1	0.02	1	0.28
VLA	4	0.96	4	2.53*	4	1.29	4	0.53
Wind	1	2.47	1	3.18	1	1.06	1	0.05

Log RMS Glideslope Error

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	1.07	1	0.86	1	0.34	1	0.35
VLA	4	0.50	4	2.29*	4	1.98	4	1.16
Wind	1	0.05	1	1.40	1	1.28	1	0.23

Percent Time-on-Tolerance Lineup (± 0.5 deggrees) and Glideslope (± 0.45 degrees)

Source	6000-4500 df	6000-4500 F	4500-3000 df	4500-3000 F	3000-1000 df	3000-1000 F	1000-Ramp df	1000-Ramp F
Experience	1	2.09	1	2.63	1	0.24	1	0.17
VLA	4	3.84**	4	1.95	4	2.36*	4	1.69
Wind	1	170.17***	1	2.53	1	3.12	1	0.04

* $p < .10$
** $p < .05$
*** $p < .01$

TABLE 8. Means for Glideslope Performance Measures for the Four Approach Segments: VLA Conditions

Percent Time-on-Tolerance Glideslope (± 0.3 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	91	79	70	58
Strobe	90	80	68	61
Crossbar	91	66	63	59
Searchlight	95	82	69	63
Cross/Search	88	72	61	58

RMS Glideslope Error (Geometric Means-feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	10.8	12.2	9.7	5.4
Strobe	10.3	11.4	9.9	5.0
Crossbar	11.3	15.6	11.5	5.3
Searchlight	10.5	11.5	10.2	4.9
Cross/Search	12.0	13.9	11.2	5.7

Percent Time-on-Tolerance Glideslope (± .45 degrees) and Lineup (± 0.5 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	56	52	46	40
Strobe	55	51	49	38
Crossbar	65	60	58	44
Searchlight	60	54	56	51
Cross/Search	66	63	57	44

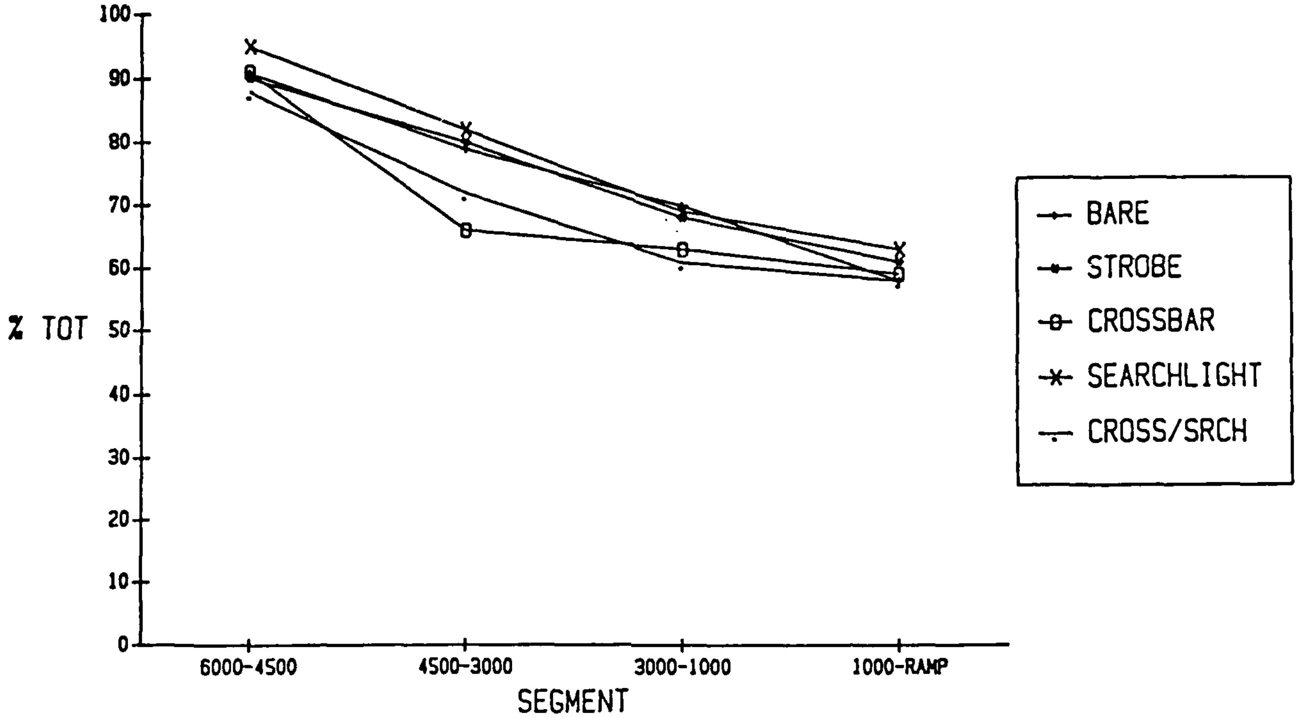


Figure 5. Percent time-on-tolerance glideslope (+/-0.3 degrees) across flight segments for the VLA conditions.

Although glideslope performance with the crossbar system was negatively affected in the middle of the approach, Fig. 6 shows that in overall performance (composite of glideslope and lineup control), the crossbar was still superior to the bare deck. This trend was not as statistically reliable (Table 7) as lineup performance alone (Table 5). In addition, overall performance under the searchlight condition parallels lineup performance results. None of the other experimental factors (experience level and wind) appeared to have a direct effect on glideslope performance.

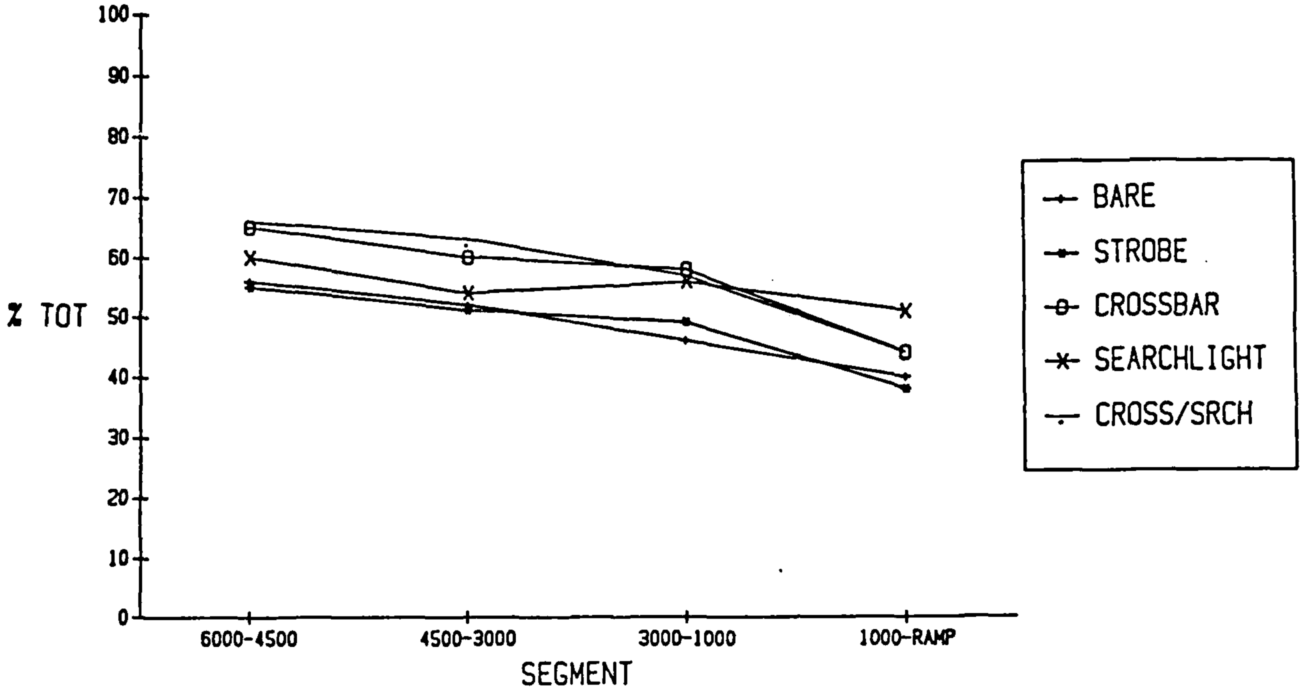


Figure 6. <u>Percent time-on-tolerance glideslope (+/-0.45 degrees) and lineup (+/-0.5 degrees) across flight segments for the VLA conditions</u>.

TOUCHDOWN PERFORMANCE

Main effects for touchdown performance measures are summarized in Table 9. The effects of VLA were only marginally significant ($\underline{p} < .10$) for the measures of wire caught and lateral drift (Table 9). Means for wire caught and lateral drift at touchdown by VLA conditions are shown in Table 10. Mean wire caught favored the searchlight condition (based on a three wire trap being optimum performance), and pilots tended to have a larger right-to-left drift at touchdown with the combination crossbar/searchlight (Table 10).

The lateral drift effect is considered to be of little practical significance since absolute lateral drift does not show a significant effect for VLA conditions. The mean lateral drift effect simply reveals a bias tendency (as opposed to absolute differences) and examination of Table 10 suggests that this bias tendency difference is small in magnitude. The practical size of the wire-caught effect is

TABLE 9. Summary of Touchdown Performance Effects

Wire

Factor	df	F
Experience	1	0.88
VLA	4	2.21*
Wind	1	0.01

Landing Performance Score

Factor	df	F
Experience	1	2.32
VLA	4	0.68
Wind	1	1.28

Distance from Centerline

Factor	df	F
Experience	1	3.07
VLA	4	1.33
Wind	1	122.34***

Distance from Centerline (Absolute)

Factor	df	F
Experience	1	0.33
VLA	4	0.33
Wind	1	1.16

Lateral Drift

Factor	df	F
Experience	1	0.36
VLA	4	2.18*
Wind	1	7.47**

Lateral Drift (Absolute)

Factor	df	F
Experience	1	0.65
VLA	4	1.47
Wind	1	5.74**

Angle of Attack

Factor	df	F
Experience	1	0.01
VLA	4	0.84
Wind	1	7.62**

Vertical Velocity

Factor	df	F
Experience	1	0.16
VLA	4	1.36
Wind	1	4.70*

* $p < .10$
** $p < .05$
*** $p < .01$

also small and is not supported by other measures of touchdown wire trap efficiency, including the landing performance score, number of wire traps, and number of bolters. The frequency of three wire traps and bolters under the VLA conditions are shown in Table 11. Chi Square analyses did not reveal any significant difference between the groups.

TABLE 10. Means for Wire Caught and Lateral Drift at Touchdown: VLA Conditions

VLA	Wire Caught Means	Lateral Drift Means
Bare Deck	2.38	0.67
Strobe	2.45	0.53
Crossbar	2.51	1.20
Searchlight	2.69	0.96
Crossbar/Searchlight	2.53	1.56

TABLE 11. Frequency of Three Wires Trapped and Bolters (missed wire): VLA Conditions

VLA	Number of Three-Wire Traps	Number of Bolters
Bare Deck	37	7
Strobe	41	10
Crossbar	44	12
Searchlight	37	13
Crossbar/Searchlight	36	10

AIRCRAFT CONTROL

Table 12 presents the means for TOT Angle-of-Attack (AOA) and RMS roll across the four flight segments. These means show that AOA performance was not affected by VLA conditions, and that RMS roll error was substantially higher during the far and middle segments of the carrier approach when the crossbar system was active. The analysis-of-variance summaries presented in Table 13 confirm this. This supports the hypothesis that the crossbar system is giving the pilots additional lineup cues to which they are attending, and improved lineup performance is the result of this increased roll activity. The effect can be seen in the far and middle segments of the approach in parallel with the lineup performance results. The results also supports the notion that some extra "work" is required to obtain the improved lineup performance, and may explain why glideslope performance decreased slightly along with improved lineup performance.

EFFECT SIZE

Percent of variance accounted for in the data (eta square) by the experimental factors for selected lineup, glideslope, and touchdown performance measures are shown in Table 14. For lineup approach performance across all segments, the VLA effect accounted for just under three percent of the variance (four percent in the middle). For wire caught and lateral drift at touchdown, the VLA effect accounted for 6.4 percent and 1.1 percent of the variance respectively. For glideslope control, the VLA effect accounted for one percent of the variance across flight segments. Wind had the largest effect on lineup performance accounting for over five percent of the variance across flight segments (13.4 percent in the far segment). Experience level accounted for little of the experimental variance.

Although it is arbitary to associate specific eta squared values with "small," "moderate," and "large" effect sizes, one guideline is given by Cohen (17). He associates eta squared values of 1 percent, 6 percent, and 11 percent with small, medium and large effects respectively. Based on the results of this experiment, the VLA effects for the performance measures tested can be said to be between "small" and "moderate." Wind had a large effect in the far segment but averaged a moderate effect across flight segments.

TABLE 12. Means for Time-on-Tolerance Angle of Attack and RMS Roll Error Across Segments: VLA Conditions

Percent Time-on-Tolerance Angle of Attack (± 1 Unit)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	99	91	89	78
Strobe	97	93	89	71
Crossbar	99	94	88	72
Searchlight	99	95	87	77
Cross/Search	98	87	84	74

RMS Roll Error (Geometric Means-degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Bare Deck	2.20	2.28	2.29	3.11
Strobe	2.26	2.38	2.54	3.08
Crossbar	2.80	2.79	2.89	3.28
Searchlight	2.29	2.47	2.68	3.24
Cross/Search	2.93	2.98	3.11	3.40

TABLE 13. Analysis-of-Variance Summary for Time-on-Tolerance Angle of Attack and RMS Roll Error

Percent Time-on-Tolerance Angle of Attack (± 1 unit)

	6000-4500		4500-3000		3000-1000		1000-Ramp	
Source	df	F	df	F	df	F	df	F
Experience	1	2.43	1	0.01	1	0.18	1	5.00
VLA	4	0.75	4	1.12	4	0.97	4	1.51
Wind	1	1.17	1	0.12	1	0.02	1	1.53

Log RMS Roll Error

	6000-4500		4500-3000		3000-1000		1000-Ramp	
Source	df	F	df	F	df	F	df	F
Experience	1	0.33	1	0.80	1	0.24	1	0.30
VLA	4	11.66**	4	9.30**	4	6.19**	4	0.91
Wind	1	17.66**	1	2.54	1	5.45**	1	12.69**

** $p < .01$

TABLE 14. Percent of Variance Accounted for in the Data (ETA^2) for Selected Performance Measures

Percent Time-on-Tolerance Lineup (± 30 feet)

Source	6000-4500 Eta^2	4500-3000 Eta^2	3000-1000 Eta^2	1000-Ramp Eta^2
Experience	0.7	2.6	0.0	0.0
VLA	1.0	3.4	5.0	2.1
Wind	9.5	2.2	4.6	1.7

Percent Time-on-Tolerance Lineup (± 0.5 degrees)

Source	6000-4500 Eta^2	4500-3000 Eta^2	3000-1000 Eta^2	1000-Ramp Eta^2
Experience	0.9	1.8	0.3	0.3
VLA	1.3	3.9	3.7	0.7
Wind	17.3	3.6	3.7	0.2

Percent Time-on-Tolerance Glideslope (± 0.3 degrees)

Source	6000-4500 Eta^2	4500-3000 Eta^2	3000-1000 Eta^2	1000-Ramp Eta^2
Experience	2.0	1.6	0.0	0.7
VLA	0.1	2.5	1.1	0.3
Wind	0.3	0.4	0.2	0.0

Touchdown Measures

Source	Wire Caught Eta^2	Lateral Drift Eta^2
Experience	1.3	0.3
VLA	6.4	1.1
Wind	0.0	1.1

PILOT OPINION

Questionnaires were administered to each pilot during and at the end of the experiment. The results of these questionnaires are summarized in Appendix E. In general, pilots liked the strobe light, although their performance data did not show that it affected lineup control. Some pilots found the searchlight useful as a lineup aid, while others did not. Many were concerned of the possibility of the searchlight inducing vertigo if the pilot boltered. Most pilots indicated that the crossbar provided the best lineup information and helped in lineup performance although at some expense of glideslope control. Most pilots did not like the combination crossbar/searchlight. They indicated an information/visual overload and tended to use the crossbar which gave them the best lineup information.

In addition to pilot comments, each pilot was asked to order the effectiveness of each set of conditions for aiding the carrier landing task. They rated the VLA conditions in terms of "easy" or "difficult" to fly, where "1" represented the easiest to fly and "5" the most difficult to fly. The results of this survey are presented in Table 15. The pilots, regardless of experience level, rated the combination crossbar/searchlight the most difficult condition to fly, followed by the bare deck (no VLAs). All pilots rated the strobe light condition the easiest to fly, and the crossbar condition the second easiest to fly.

TABLE 15. Mean Ratings of Task Difficulty

VLA Condition	All Pilots (n = 10)	Low Experience (n = 5)	High Experience (n = 5)
Crossbar/Searchlight	4.1	4.4	3.8
Bare Deck	3.8	3.8	3.8
Searchlight	3.1	3.2	3.0
Crossbar	2.8	3.0	2.6
Strobe Light	1.6	1.4	1.8

POST-EXPERIMENT SUPPLEMENTARY DATA COLLECTION

In their debrief questionnaire, two pilots suggested an artificial horizon as a lineup aid. They indicated that lineup control at night is much more difficult because of the lack of a horizon to obtain feedback on bank angle corrections and to maintain level flight. Thus, as a preliminary examination, two searchlights (each 900 ft in length) were added to the aft end of the carrier extending left and right from the carrier to create an artificial horizon. Data was collected at the end of the experiment on two pilots who flew twelve night carrier approaches each with the artificial horizon and no other VLAs except the strobe light.

Table 16 shows that the last two pilots' lineup performance with the artificial horizon was comparable to their performance with the crossbar. Although it is interesting, no conclusions can be drawn from these data. It was only a preliminary examination based on two pilots and not part of the controlled experiment.

TABLE 16. Means for Percent TOT Lineup ($\pm$ 0.5 degrees) for the Two Pilots Post-Tested with the Artificial Horizon

	6000-4500	4500-300	3000-1000	1000-Ramp
Bare Deck	64	67	67	59
Crossbar	72	76	90	69
Artificial Horizon	82	84	85	69

DISCUSSION

The purpose of this study was to evaluate the degree to which various visual landing aid (VLA) configurations facilitate lineup performance in the final approach segment of the night carrier landing task. However, the carrier landing task is a multidimensional task, and interpretation of results should be based on all dimensions of performance (e.g., lineup control, glideslope control, etc.). Nevertheless, lineup performance was the most important consideration and was affected the most by the VLAs in the experiment. Thus, the discussion that follows will emphasize lineup control and bring to bear other relevant information.

EXPERIMENTAL FACTORS

Visual Landing Aids

The analyses of the sampled lineup performance measurements indicate several observations for the VLA configurations. Specifically:

- The manipulation of VLA condition had a significant effect on lineup time-on-tolerance and RMS error measures. Lineup performance was particularly facilitated by the presence of the crossbar and crossbar/searchlight configurations in the far and middle segments of the approach. The substantial improvement in lineup control at the start and in the middle did not carry over into the close-in segment where the crossbar system was inoperative. There was no difference in lineup performance between the crossbar and crossbar/searchlight conditions.

- Lineup performance under the searchlight condition tended to lie between performance with the crossbar and the bare deck conditions in the far and middle segments of the approach. The searchlight did enhance lineup performance in the middle-close segment (3000-1000 feet) but not as much as the crossbar. The searchlight did not significantly improve performance at the ramp or at touchdown.

- The strobe light did not have any effect on lineup performance.

The utility of the various VLA configurations in aiding performance can be evaluated in light of the concepts of display-control synthesis (18), stimulus-response compatibility (19), and the perceptual salience of optical information (20). Although these various approaches to the

adequacy of perceptual information for the control of behavior contain conflicting assumptions regarding underlying cognitive processes, they contain a common theme. Perceptual information (whether originating from the environment, a pictorial display, or flight instruments) will be of use to the extent to which it is, first of all, in close correspondence with the control needs of the observer and, secondly, readily perceivable.

The differential effects on performance of the five VLA configurations evaluated in this experiment can be assessed in terms of the ease with which perceptual information specifying lineup deviation can be obtained from each. In general, the "goal" of the pilot can be conceived as the maintenance of a perceptually optimum state of affairs throughout all phases of the approach and landing. In controlling glideslope, for example, the pilot carries out control activities in order to maintain the FLOLS "meatball" at a position midway between the datum bars. Maintaining this perceptual state of affairs throughout the approach will result in a successful landing, assuming the pilot is able to maintain an appropriate position relative to the centerline of the landing area.

The searchlight and strobe conditions can both potentially specify lineup deviations, although the results of this study indicate that the information the strobe affords is apparently less effective than that in the other VLAs. Lineup deviations in the former two conditions are specified in terms of angular deviations between a perceived centerline on the landing area extending in the direction of the pilot's motion (X dimension) and perceivable features on the ship (e.g., forward and aft deck lights) which extend in a direction perpendicular to the pilot's path of motion (Y dimension). Maintaining perceived perpendicularity between these elements will result in adequate control of lineup. However, the usefulness of these VLA conditions may ultimately lie in the ability of the pilot to detect very slight angular shifts of the centerline from perpendicularity. Deviations of less than five degrees, though operationally significant, may lie below the threshold capabilities of the visual system, particularly under conditions of degraded visibility.

The advantage of the crossbar configuration appears to lie primarily in terms of its ease of interpretation (stimulus-response compatibility) and the lack of demand placed on the acuity of the visual system. In addressing the first point, the information content of the display was intuitively obvious to the pilots, allowing them to make control adjustments without significantly contributing to their attentional workload. Secondly, this type of display does not require sensitivity to subtle transformations in visual stimulation, as in the case with the searchlight and strobe configurations. The sudden appearance of areas of high luminance in

the visual field has previously been demonstrated to result in "visual capture" (21), an involuntary shift of the line of sight. Therefore, the crossbar configuration has the advantage of not requiring an intensive search for information on the part of the pilot. Terminating the display when the pilot transitions to within 1500 feet of the carrier's stern prevents an adverse effect of visual capture while the pilot is attending to information on the deck.

It is apparent that the crossbar improved the ability of the pilots to set up and start the approach on lineup, although the substantial improvement in lineup control did not carry over into the close-in segment. The lack of an in-close benefit may be due to the fact that the crossbar presentation was terminated when the aircraft was 1500 feet from the ramp. Nevertheless, a good start and better performance in the middle is obviously beneficial. Even though this benefit could not be statistically determined in-close, it is reasonable to state that the occurrence of an occasional bad or dangerous lineup situation in-close would be reduced as a result of the crossbar system.

The suggestion that the searchlight seemed to be useful in the near segments, while the relative advantage of the crossbar faded makes it tempting to recommend some sort of crossbar/searchlight combination as potentially optimal. However, a version of this was tested in the study and resulted in performance no different from the crossbar alone. In particular, it should be pointed out that in the in-close segment (1000 feet. to the ramp) the searchlight alone was functional under the crossbar/searchlight combination, making it identical with the searchlight only experimental condition in the segment. Yet, the data show no difference between the crossbar and crossbar/searchlight conditions in the segment.

Taking this information into account, along with strong pilot comment against the crossbar/searchlight combination (visual overload), and the information that the searchlight does not generally improve performance under relatively difficult wind conditions, resulted in the conclusion that the crossbar system alone must be recommended as the most effective visual aid for lineup performance improvement. Further, we believe that the crossbar lights could be left on somewhat longer, perhaps with modified sensitivity, and that this would provide added lineup improvement in close and still avoid the "visual capture" phenomenon discussed earlier.

The data showed that performance under the crossbar conditions was not affected by wind conditions in the far and middle segments of the approach, while performance under the bare deck, strobe, and searchlight conditions was markedly worse under the more difficult wind condition. In fact, under the axial wind condition there were little or no differences

between VLA conditions. This finding strongly indicates that the crossbar system is most effective when it is needed most, i.e., difficult environmental conditions.

The advantage of the crossbar conditions dissipated in close and at touchdown as previously noted. Performance enhancement with the searchlight alone, in contrast, seemed to increase relative to the bare deck in the near segments. The searchlight, as implemented in the experiment, did not provide substantive visual cueing in the far and middle segments according to pilot comments. Closer in, particularly the middle-close segment (3000-1000 feet), it seemed to provide meaningful lineup cue enhancement. Still, the crossbar system resulted in better performance in this segment, and although the data suggested the searchlight gave the best performance in close (1000 feet to the ramp), the effect in this segment was not signficant.

Although we cannot recommend further consideration of the searchlight as implemented in this experiment, it should be noted that there was a substantial difference between the searchlight concept described by the Naval Air Engineering Center (NAEC) (see Fig. A-4) and the implementation in the VTRS. The original concept called for a searchlight beam extending aft from the centerline of the angle deck. The intention was to provide path delineation visible over the full length of the approach. In this configuration the searchlight path would always be visible over the nose of the aircraft. The pilots' lineup task would thereby be reduced to keeping the aircraft over the line. Any deviation would be quickly apparent as a linear offset. In the forward facing searchlight condition, the deviation from lineup requires a judgment of apparent angular change. This judgment is more difficult and may not have the sensitivity inherent in a rear facing searchlight condition that extends well beyond the 900 feet used in this experiment.

It must be pointed out that there were attempts to implement a 900 feet aft-facing searchlight in preliminary work for this experiment. The concept was rejected by test pilots who indicated that the searchlight was obscuring their view of other lineup cues and was not particularly useful. This may have been a problem with simulator implementation of the 900 feet length, or may have been a problem that could have been acceptably solved with further development.

In addition to the extended rear facing searchlight condition, other searchlight configurations are also possible that could improve lineup performance. For example, in this study, we conducted a preliminary examination of an artificial horizon (two searchlights each 900 feet long extending left and right from the aft end of the carrier). Although no definite conclusions can be drawn from these data, the

artificial horizon appeared to be very successful in enhancing lineup performance (comparable or better than the crossbar system), and combined with an extended rear facing searchlight could prove to be an optimum configuration.

Another configuration that was used with great success in airport lighting systems during World War II which could be adapted to the carrier deck consists of two pairs of vertically oriented searchlights bracketing each end of the runway (i.e., one at each corner) (22). The angular perspective provided could improve lineup performance at all ranges.

Although the VLAs were configured to assist lineup control, glideslope control is the most critical element in the carrier approach. Thus, the effects of the VLAs on glideslope performance was of considerable interest. For example, the VLAs may have assisted glideslope control if the pilot could shift more of his attention from lineup control. On the other hand, the VLAs may have attracted some of the attention normally paid to the FLOLS display in which case glideslope could suffer.

The data indicated that the searchlight and strobe did not significantly affect glideslope performance. However, glideslope performance with the crossbar system was slightly worse in the middle compared to the bare deck. It appears that the improved lineup performance in the middle with the crossbar tends to come at some expense of glideslope control. However, although the trend was apparent, it was a weak effect (p < 0.10). The crossbar system was a novel device and may have attracted some of the pilot's attention normally paid to the FLOLS display. However, with experience and practice, it is our opinion that pilots would learn to scan the crossbar system rather than fixate or focus their attention on it with an accompanying diminishment of the negative glideslope effect. The searchlight was also, of course, novel to the pilots, but provided a kind of enhancement of an existing cue rather than an additional or "new" visual display requiring added attention in order to learn to fly it.

Final outcome or touchdown is of critical importance when evaluating carrier landing performance. However, despite their value as operationally relevant scores, capture values (touchdown scores) tend to have relatively low statistical power for detecting effects. Nevertheless, touchdown scores are the final outcome and must be considered in any evaluation of carrier landing visual performance aids. The results indicated that the VLA effects on touchdown performance were minimal. Only mean wire caught and lateral drift at touchdown were even marginally significant (p < .10) and no pattern emerged which could favor any of the VLAs. Thus, it must be concluded that touchdown performance was not appreciably or reliably affected by the visual aids tested in this

experiment. It is possible that more difficult environmental conditions could have produced a touchdown effect, but this is doubtful, particularly with the crossbar system which was turned off at 1500 ft from the ramp. In any case, there are no data on touchdown performance from this experiment which would lend support to any of the tested visual landing aids.

Experience Level

The primary reason for including experience level in this experiment was to determine whether experience in night carrier landing would result in varying performance under different VLA conditions. Previous research at the VTRS had shown that augmenting the FLOLS display with rate information improved glideslope performance of experienced carrier pilots, (4) but was not of benefit to inexperienced pilots (12). In the present experiment there were no performance differences noted under the different VLA conditions due to experience level. Based on this information, the recommendation of a VLA condition can be based on overall performance regardless of experience level.

PILOT OPINION

All the pilots had favorable opinions of the strobe light (that it reduced workload and made lineup easier), and they rated this VLA as "easiest to fly." However, the data did not support this. The strobe light had no effect on lineup or any other dimensions of performance. Pilots generally agreed that the crossbar configuration enhanced lineup performance, and it was rated second "easiest" to fly. Pilots also generally agreed that glideslope control suffered with the crossbar and that they tended to chase the crossbar. Simulator performance data supports their observations. It would seem that a VLA rated clearly relatively less "difficult" does not necessarily mean that better performance will result. In this case, some extra "work" resulted in better performance.

Pilots had mixed attitudes towards the searchlight. Some thought the extension of the centerline helped in lineup control, while others did not find it useful. However, pilots generally agreed that the searchlight could be dangerous tactically, in that it could induce vertigo on a bolter. However, the feeling of vertigo could be inherent to the flight simulator and not in the real environment, or the feeling of vertigo could have been a result of the manner in which the searchlight was modelled.

It is interesting to note that pilots rated the crossbar/searchlight combination lowest (most difficult to fly) in relation to the other VLA configurations. Pilots generally agreed that the crossbar/searchlight combination presented an information overload and that they tended to ignore the

searchlight and attended strictly to the crossbar for lineup information. The performance data indicate no differences between the crossbar/ searchlight combination and the crossbar condition.

Artificial Horizon

Although the test with the artificial horizon was only a preliminary examination, and not part of the controlled experiment, the results were interesting. Lineup performance of the two pilots tested with the artificial horizon was comparable to their performance with the crossbar. Discussions with the pilots revealed that some consider the lack of a horizon at night a primary contributing factor to increased difficulty in lineup control. Without a horizon, it is more difficult to make accurate lineup corrections (judge appropriate bank angle). It is sometimes difficult to determine if the aircraft has rolled out and is flying straight without scanning the instruments. A bank angle of two to three degrees may not be noticeable without a horizon. Thus, from our preliminary examination, an artificial horizon might be worth further investigation.

CONCLUSIONS/RECOMMENDATIONS

Three of the four experimental VLA configurations (crossbar, searchlight, and crossbar/searchlight combination) resulted in significant improvements in night carrier landing approaches relative to the bare deck control condition. Each of these VLA conditions contributed some effective visual cues for one part or another of the night carrier landing task. The dilemma is to embody the cues essential to the carrier landing task in a display configuration that avoids the deficiencies and operational pitfalls of those tested in the present experiment. These cues must be embodied in a display that does not make one aspect of control easier at the expense of others, does not induce disorientation, or impose other operational problems at any point.

Based on the results of the experiment, the crossbar system emerges as a very promising VLA for improving lineup performance. The crossbar improved the ability of the pilots to set up and start the approach on lineup, and substantially improved performance through the middle of the approach, although the substantial improvement did not carry over into at-the-ramp and touchdown performance. The lack of an in-close benefit may be due to the fact that the crossbar system was terminated when the aircraft was 1500 feet from the ramp. Nevertheless, a good start and better lineup performance in the middle is obviously beneficial. Implementation of the crossbar system in the fleet may aid in reducing the task demands imposed on pilots in the night carrier landing situation, particularly under adverse environmental conditions when task demands are maximized. Although glideslope performance in the middle of the approach did suffer slightly with the crossbar system, practice and pilot awareness should avoid any possible negative consequences from the crossbar system.

Furthermore, it is possible that the crossbar system tested in the present experiment was not optimum, and further refinement is needed. Simulator evaluation or field testing could determine the optimum configuration of the system (i.e., the spacing of the lights on either side of the center green light, and the angular increments of their beams fanning outward). In addition, in subsequent testing, consideration should be given to keeping the crossbar system operational for a longer period of time and measuring its effect close-in along with any tactical problems.

The searchlight also emerges as a possible VLA for improving lineup performance. However, as configured in the experiment, the searchlight had its drawbacks. Far and mid-range lineup could and should be much better and its potential adverse effects during bolter recoveries would not be operationally acceptable. Therefore, we do not recommend further consideration of a forward-facing searchlight. The previous discussion indicated a number of other searchlight configurations (extended rear facing searchlight visible over the entire length of the approach; artificial horizon; and vertically oriented searchlights bracketing each corner of the runway) that have the potential of improving lineup in all ranges without a corresponding tactical problem during bolter recoveries. These should be examined before a final recommendation can be made on a searchlight configuration.

The crossbar/searchlight combination also substantially improved lineup performance in the far and mid-range of the approach. However, performance was no different than with the crossbar alone. This was disappointing, particularly for close-in performance, when the searchlight was still active after the crossbar lights had been terminated. Furthermore, pilots did not like the crossbar/searchlight combination. They generally agreed that it presented an information/visual overload and that they tended to ignore the searchlight and attended to the crossbar for lineup information. Thus, the crossbar/searchlight combination as configured in this experiment should not be considered further.

The strobe light did not have any effect on lineup performance. However, this result does not lead to the suggestion that strobe lighting should be removed from current fleet deck lighting configurations. It is probably a useful aid in helping pilots spot the deck and centerline in foul weather and pilot acceptance is high. On the other hand, it should not be thought of as an effective lineup aid once the approach has started and should not be considered for further development as a lineup aid.

REFERENCES

1. Hyman, A., "Research in visual perception for carrier landing." Visual Perception, Vol. 2, pp. 2-7, 1972.

2. Brictson, C.A., "Analysis of F-4 aircraft day and night carrier approaches." Aerospace Medicine, Vol. 38, No. 12, pp. 1219-1224, December 1967.

3. Perry, B.L., Optical guidance systems: Analysis, design and development, Report No. 6581, Naval Research Laboratory, Washington, DC, 1967.

4. Lintern, G., Kaul, C.E., and Collyer, S.C., "Glideslope descent-rate cuing to aid carrier landings." Human Factors, Vol. 26, No. 1, pp. 667-676, February 1984.

5. Brictson, C.A., Measures of pilot performance: Comparative analysis of day and night carrier recoveries, Dunlap and Associates, Santa Monica, CA, June 1966.

6. Brictson, C.A., Burger, W.J., and Kennedy, R.S., "Predicting the quality of pilot landing performance during night carrier recovery." Aerospace Medicine, Vol. 42, No. 1, pp. 16-19, January 1971.

7. Martin, E.L. and Cataneo, D.F., Computer generated image: Relative training effectiveness of day versus night visual scenes, AFHRL TR-79-56, USAF Human Resources Laboratory Operations Training Division, Williams AFB, AZ, 1980.

8. Naval Air Engineering Center, Study of functional requirements for visual landing aids, NAVAIRENGCEN Report NAEC-91-8052, Naval Air Engineering Center, Naval Air Station, Lakehurst, NJ, May 1984.

9. Naval Air Engineering Center, Summary of glideslope and linear cue concepts proposed for flight simulator evaluation, NAVAIRENGCEN Report No. 91-1875, Naval Air Engineering Center, Naval Air Station, Lakehurst, NJ, March 1985.

10. Hennessy, R.T., Human factors assessment of Visual Landing Aid (VLA) concepts for simulator evaluation, Technical Report MTI-8505, Monterey Technologies, Carmel, CA, October 1985.

11. Westra, D.P., Simon, C.W., Collyer, S.C., and Chambers, W.S., Simulator design features for carrier landing: I. Performance experiment, NAVTRAEQUIPCEN 78-C-0060-7, Naval Training Equipment Center, Orlando, FL, September 1982.

12. Westra, D.P., Investigation of simulator design features for carrier landing: II. In-simulator transfer of training, NAVTRAEQUIPCEN 81-C-0105-1, Naval Training Equipment Center, Orlando, FL, December 1982.

13. Collyer, S.C. and Chambers, W.S., AWAVS, a research facility for defining flight trainer visual requirements. Proceedings of the Human Factors Society 22nd Annual Meeting, Human Factors Society, Santa Monica, CA, 1978.

14. Sheppard, D.J., Visual and part-task manipulations for teaching simulated carrier landings, NAVTRAEQUIPCEN 81-C-0105-9, Naval Training Equipment Center, Orlando, FL, March 1985.

15. Westra, D.P., Lintern, G., Sheppard, D.J., Thomley, K.E., Mauk, R., Wightman, D.C., and Chambers, W.S., Simulator design and instructional features for carrier landing: A field transfer study, NAVTRASYSCEN 85-C-0044-22, Naval Training Systems Center, Orlando, FL, June 1986.

16. Levine, D.W. and Dunlap, W.P., "Power of the F test with skewed data: Should one transform or not?" Psychological Bulletin, Vol. 92, pp. 272-280, June 1982.

17. Cohen, J., Statistical power analysis for the behavioral sciences, Academic Press, New York, NY, 1977.

18. Roscoe, S.N., Aviation psychology. The Iowa State University Press, Ames, IA, 1980.

19. Wickens, C.D., Engineering psychology and human performance. Charles E. Merrill Publishing Co., Columbus, OH, 1984.

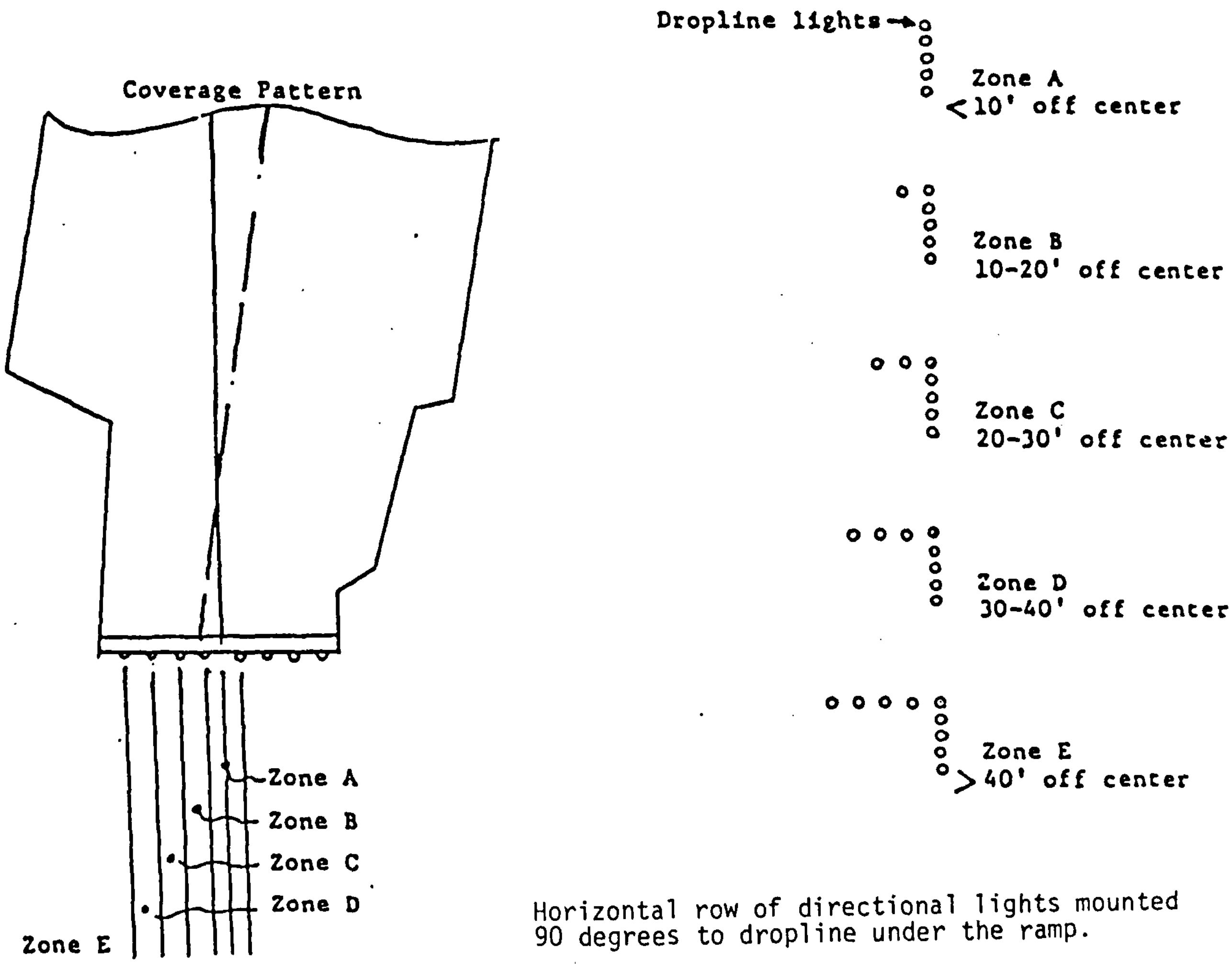
20. Gibson, J.J., The ecological approach to visual perception. Houghton-Mifflin Co., Boston, MA, 1979.

21. Kaufman, L., Perception: The world transformed. Oxford University Press, New York, NY, 1979.

22. Roscoe, S.N., Personal communication, 1987.

APPENDIX A

VISUAL LANDING AID LINEUP CONCEPTS (9)



Horizontal row of directional lights mounted 90 degrees to dropline under the ramp.

Figure A-1. <u>Crossbar lineup system</u>.

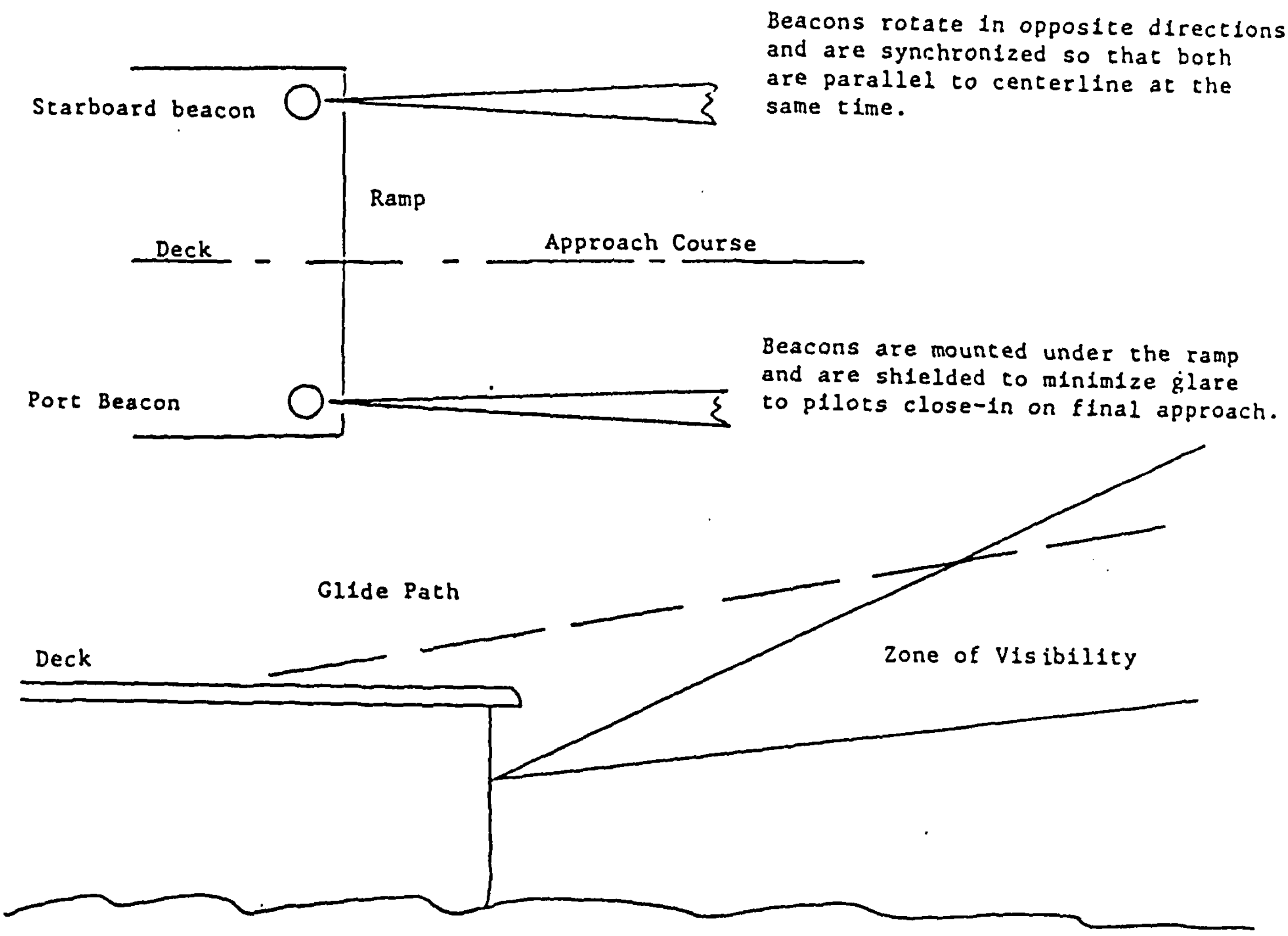


Figure A-2. Contra-rotating lineup beacons.

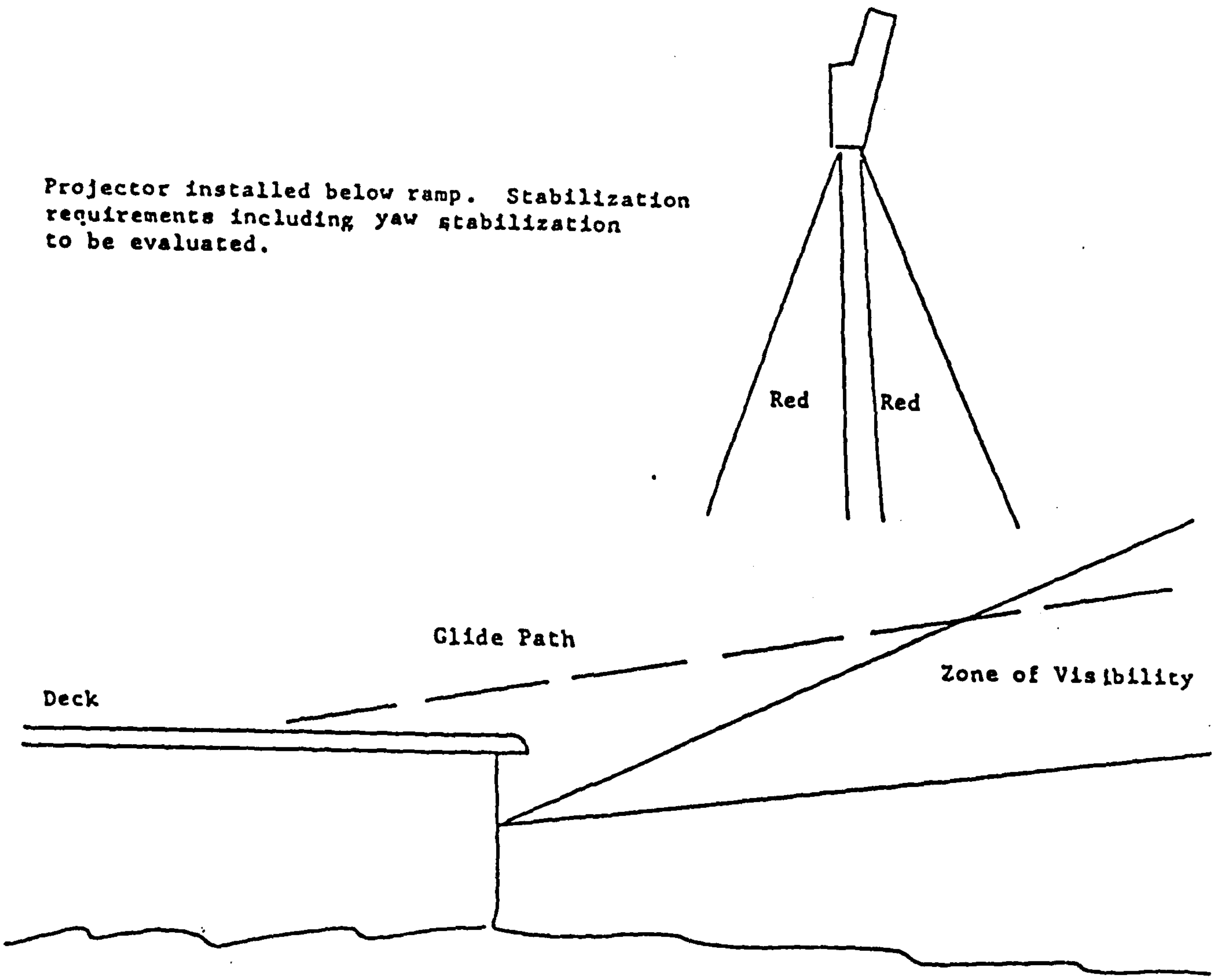
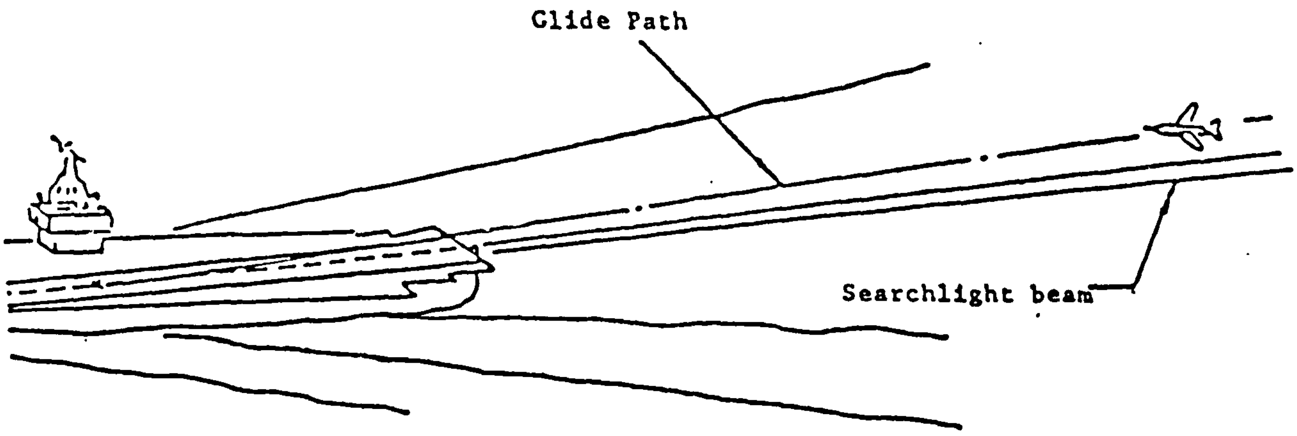


Figure A-3. Double-beam lineup system.



The beam must be pointed down at the water same distance aft to avoid the possibility of light hitting the pilot in the eye if he flies too low. This still poses a possible navigation hazard.

Figure A-4. Searchlight-Simulated runway extension.

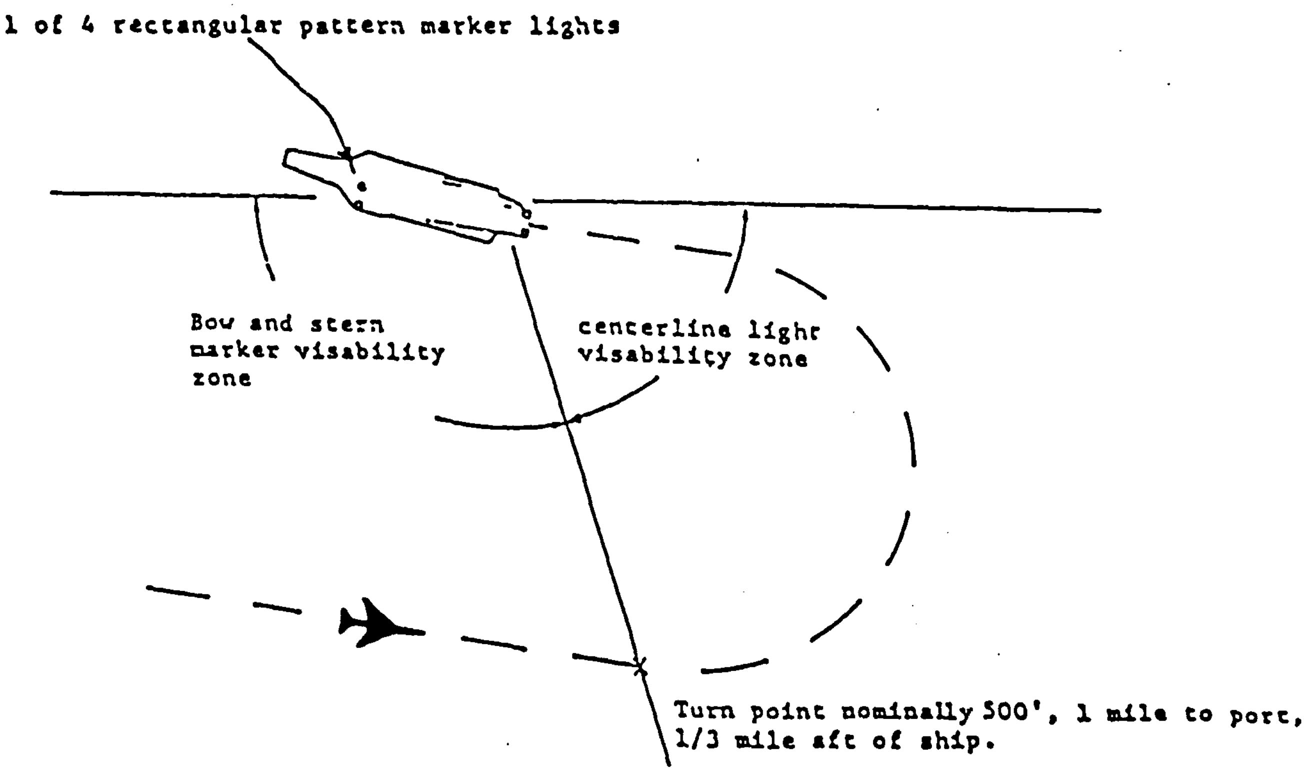


Figure A-5. Racetrack cue lineup aid.

APPENDIX B

FRESNEL LENS OPTICAL LANDING SYSTEM

The Fresnel Lens Optical Landing System (FLOLS) provides primary glideslope displacement information for a carrier approach to landing. It consists of light sources behind five vertically stacked Fresnel lenses that are situated beteween two horizontal light arrays known as the datum bars. The array of lenses and lamps provides a virtual image which appears to the pilot as a single light located 150 feet behind the datum bars. This light is known as the meatball. It is visible to the pilot through the center lens and is seen as level with the datum bars when the aircraft is on glideslope. As the aircraft moves more above or below the glideslope, the meatball is seen through higher or lower Fresnel lenses to give the appearance of moving vertically above or below the line of the datum bars. Each fresnel lens subtends 20.45 minutes of arc, so the meatball is visible to the pilot when he is within plus or minus 0.9 degrees of the glideslope.

For a carrier approach, the pilot attempts to follow a designated glideslope (usually 3.5 degrees) by keeping the meatball level with the datum bars, so that a hook attached to the tail of the aircraft will contact the landing deck midway between the second and third of four arrestment cables. These cables (more frequently referred to as wires) are stretched across the landing deck at different distances from the ramp. Under the aircraft's momentum the hook travels forward to snag the third wire for a trap (arrested landing). The first or second wire may be caught on a low approach and the fourth on a high approach. Very low approaches can result in a ramp strike, while high approaches can result in a bolter (a missed approach because of touchdown beyond the wire arrestment area).

APPENDIX C

LIST OF PERFORMANCE MEASURES COMPUTED FOR EACH TRIAL TASK SEGMENTS AND STATISTICAL ALGORITHMS

<u>Task Segments</u>

6000 - 4500 feet	4500 - 3000 feet
3000 - 1000 feet	1000 - Ramp

<u>Variables Measured in Each Segment</u>

Variables Measured	Summary Measures Taken of Each Variable
Angle of Attack	Root Mean Square Error
Lateral Deviation (feet)	Average or Bias Error
Glideslope (feet)	Variability Error
Roll Angle	
Pitch Angle	
Lateral Deviation (degrees)	
Glideslope (degrees)	
Roll (degrees/second)	
Pitch (degrees/second)	
Yaw (degrees/second)	

<u>Percent Time-in-Tolerance Measures in Each Segment</u>

Glideslope $\pm$ 0.6 degrees	Lineup $\pm$ 1.0 degrees
Glideslope $\pm$ 0.45 degrees	Lineup $\pm$ .5 degrees
Glideslope $\pm$ 0.3 degrees	Lineup $\pm$ 15 feet
Glideslope $\pm$ 0.45 degrees	Lineup $\pm$ 30 feet
and Lineup $\pm$ .5 degrees	Angle of Attack $\pm$ 1 unit

<u>Average Stick Movements for Each Segment</u>

Throttle	Elevator
Aileron	Pedal

Snapshot Values - Ramp	Touchdown - Values
Angle of Attack	Wire
Lateral Deviation (ft)	Roll Angle
Glideslope (ft)	Pitch Angle
Roll Angle	Hook Position Down Runway
Pitch Angle	Lateral Deviation
Lateral Deviation (deg)	Vertical Velocity
Glideslope (deg)	Angle of Attack
Roll (deg/sec)	Landing Performance Score
Pitch (deg/sec)	Lateral Drift
Yaw (deg/sec)	
Lateral Drift	

APPENDIX C (continued)

ALGORITHMS FOR THE STATISTICALLY REDUCED SUMMARY DATA

RMS error = $(\sum e_t^2/n)^{1/2}$

Bias error = e

Variable error = $(\sum (e - e_t)^2/n)^{1/2}$

where e_t = error at time t,

n = number of samples

AST[1] = $r/n \sum (|P_t - P_{t-1}|)$

where P_t = stick position at time t,

r = sampling rate,

n = number of samples

---

[1] Average stick movement per second

APPENDIX D

MEANS OF EXPERIMENTAL FACTORS

TABLE D-1. Lineup Means: Experience Level and Wind Conditions

Percent Time-on-Tolerance Lineup (± 15 feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	17	25	45	79
High Experience	23	33	48	78
Angle Wind	14	26	42	75
Axial Wind	25	32	51	82

Percent Time-on-Tolerance Lineup (± 30 feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	39	46	75	92
High Experience	45	59	77	97
Angle Wind	31	46	69	95
Axial Wind	54	59	83	98

Percent Time-on-Tolerance Lineup (± 0.5 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	58	57	60	57
High Experience	65	68	64	53
Angle Wind	45	55	55	54
Axial Wind	78	69	69	57

RMS Lineup Error (Geometric Means-feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	42.0	32.0	20.0	9.0
High Experience	37 0	25.0	18.0	9.0
Angle Wind	50.0	34.0	21.0	10.0
Axial Wind	31.0	24.0	17.0	9.0

TABLE D-2. Glideslope Means: Experience Level and Wind Conditions

Percent Time-on-Tolerance Glideslope (± 0.3 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	89	71	66	57
High Experience	94	80	67	63
Angle Wind	90	78	67	60
Axial Wind	92	74	65	60

RMS Glideslope Error (Geometric Means-feet)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	12.0	14.0	11.0	5.6
High Experience	10.0	11.7	10.0	4.9
Angle Wind	10.9	12.7	10.3	5.2
Axial Wind	10.9	13.0	10.7	5.3

Percent Time-on-Tolerance Glideslope (± 0.3 degrees)
and Lineup (± 0.5 degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	57	51	51	45
High Experience	64	62	55	42
Angle Wind	44	50	48	43
Axial Wind	76	62	58	44

TABLE D-3. Touchdown Means: VLA

	Landing Performance Score	Lateral Drift (Absolute)
Bare Deck	4.47	0.67
Strobe	4.63	0.53
Crossbar	4.44	1.20
Searchlight	4.61	0.96
Cross/Search	4.40	1.56
	Distance from Centerline	**Distance from Centerline (Absolute)**
Bare Deck	-0.06	5.33
Strobe	0.24	5.02
Crossbar	-1.16	5.17
Searchlight	-0.56	4.73
Cross/Search	0.29	5.28
	Angle of Attack	**Vertical Velocity (fps)**
Bare Deck	15.38	12.22
Strobe	15.17	12.36
Crossbar	15.12	11.79
Searchlight	15.12	12.03
Cross Search	15.30	11.79

TABLE D-4. Touchdown Means: Experience Level and Wind Conditions

	Wire	Landing Performance Score
Low Experience	2.44	4.35
High Experience	2.57	4.67
Angle	2.51	4.57
Axial	2.52	4.45

	Lateral Drift	Lateral Drift (Absolute)
Low Experience	1.17	3.02
High Experience	0.80	2.72
Angle	0.62	2.67
Axial	1.35	3.08

	Distance from Centerline	Distance from Centerline (Absolute)
Low Experience	1.47	5.34
High Experience	-1.47	4.87
Angle	-2.17	5.43
Axial	1.66	4.78

	Angle of Attack	Vertical Velocity (fps)
Low Experience	15.19	12.17
High Experience	15.25	11.90
Angle	15.34	12.22
Axial	15.10	11.86

TABLE D-5. Aircraft Control Means: Experience Level and Wind Conditions

Percent Time-on-Tolerance Angle of Attack (± 1 Unit)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	99	92	86	66
High Experience	97	92	89	83
Angle Wind	99	92	88	73
Axial Wind	98	92	87	76

RMS Roll Error (degrees)

	6000-4500	4500-3000	3000-1000	1000-Ramp
Low Experience	2.38	2.37	2.62	3.37
High Experience	2.59	2.75	2.85	3.08
Angle Wind	2.67	2.62	2.82	3.39
Axial Wind	2.31	2.48	2.65	3.06

APPENDIX E

SUMMARY OF PILOT QUESTIONNAIRES

LOW-EXPERIENCE

STROBE LIGHT: Defined centerline clearly, made centerline easier to see/scan. Helped reduce workload, but at the expense of glideslope. Helped lineup.

CROSSBAR: Helped lineup, but at the expense of glideslope if it was scanned as opposed to referenced. Increased workload. Led to overcorrection because system was "much too active."

SEARCHLIGHT: Neither postive or negative opinion -- difficult to see until in close, at which point attention switches to glideslope. Possibility of inducing vertigo once pilot has boltered. No feedback provided for lineup correction.

CROSSBAR/SEARCHLIGHT: Information overload. Not necessary to have three lineup cues. Crossbar provided the most information; glideslope control suffered.

MODERATE EXPERIENCE

STROBE: Required slightly more effort to gauge actual deviation from centerline. Decreased workload. Lineup easier.

CROSSBAR: Helped lineup in the middle by easing workload, but glideslope suffered. Tended to fixate on lineup. Took attention away from the ball. Provided opportunity to correct lineup far out. Tended to chase crossbar.

SEARCHLIGHT: Extension of centerline helped. Relative brightness compared to landing area required more concentration. Dangerous tactically, induces vertigo, adds artificial horizon on a bolter or wave off. Did not find useful.

CROSSBAR/SEARCHLIGHT: Too much information. Searchlight was dropped from scan. Had to be selective. Crossbar was easiest to interpret and gives earliest lineup indication of all VLAs.

END
DATE
FILMED
5-88
DTIC